Volume 13 AUGUST 1929 Number 8

BULLETIN
of the
American Association *of* Petroleum Geologists

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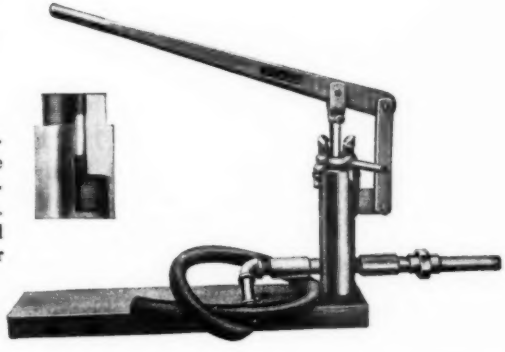

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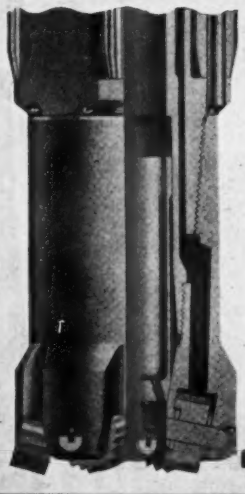

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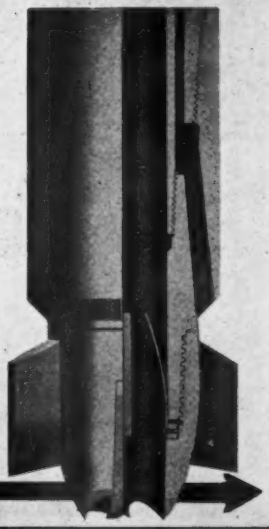

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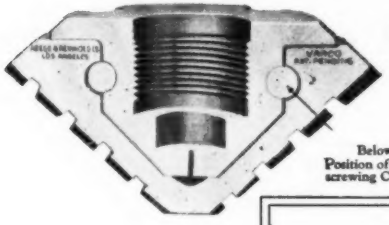

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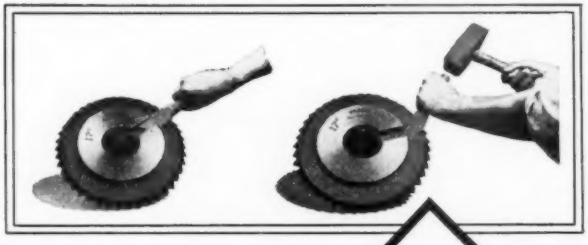

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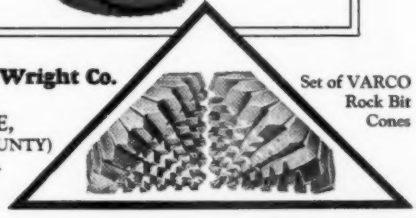

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By DONALD C. BARTON

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Volume 13 Number 8

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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

AUGUST 1929

SYMPOSIUM ON PENNSYLVANIAN AND PERMIAN STRATIGRAPHY OF SOUTHWESTERN UNITED STATES

ALEX W. McCOY, *Chairman*

FOREWORD

At the annual meeting of the American Association of Petroleum Geologists, held at Fort Worth, Texas, in March, 1929, the Program Committee, consisting of F. B. Plummer, A. R. Denison, Paul Applin, R. H. Fash, M. G. Cheney, and R. A. Liddle, chairman, offered as the principal feature of this program a Symposium on the Stratigraphy of the Permian Basin of Southwestern United States. Alex W. McCoy was chairman of the symposium during the sessions.

For the convenience of those who are interested we are publishing, in this number of the *Bulletin*, most of the contributions to this symposium. We believe that our readers will find these papers, and the succeeding discussions, of real interest and value as presenting some of the latest ideas regarding the Permian Basin province.

For their zeal and advice in the achievement of this symposium, gratitude is due to Mr. McCoy and to the Fort Worth program committee; and, in particular, credit is due to Mr. Liddle, who devoted a great deal of time and thought to soliciting the papers, encouraging the authors, editing the manuscripts, and making, not only the symposium, but also the whole program, a success.

F. H. L.

CORRELATION OF PENNSYLVANIAN FORMATIONS OF TEXAS AND OKLAHOMA[1]

RAYMOND C. MOORE[2]

Lawrence, Kansas

ABSTRACT

Detailed investigation and mapping of the Pennsylvanian rocks in Oklahoma is sufficiently advanced to permit fairly definite tracing of formations north of the Arbuckle Mountains to the type section in Kansas. Interruption of outcrops in southern Oklahoma makes correlation of the Pennsylvanian section of the Ardmore basin and of north-central Texas dependent on paleontologic evidence, lithologic characters, sequence of deposits, and relation to structure. The significant facts concerning each of these criteria are discussed briefly, and a tentative correlation of the Pennsylvanian beds from Texas to Kansas is offered. Evidence is cited pointing to at least two im-

[1]Presented before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, May 12, 1929.

[2]University of Kansas.

portant orogenic epochs during Pennsylvanian time in southern Oklahoma, the first of Pottsville (post-Morrow) age and the second in the late middle (post-Kansas City) part of the period.

INTRODUCTION

Correlation of the Pennsylvanian strata in the Mid-Continent region has occupied the attention of many workers. In view of the economic importance of the Pennsylvanian rocks of the Mid-Continent region, and especially because in recent years many geologists and paleontologists have been working in the field and laboratory on problems related to these rocks, it is perhaps strange that a fairly definite, generally accepted correlation of the sections in the respective areas should not long since have been worked out. In this instance, as in many others, added detailed knowledge has to a degree complicated rather than made more simple the task of correlation.

The classic Pennsylvanian section of eastern Kansas and western Missouri has been made well known through studies of Meek and Hayden, Swallow, Broadhead, Haworth, Adams, Girty, Beede, Prosser, Hinds, Greene, and others. In southern Oklahoma, investigations by Taff, and later, in northern Oklahoma, work by Ohern laid the groundwork of Pennsylvanian stratigraphy in that state. First Cummins and subsequently Drake did similar service in Texas. However, the past 15 years has added enormously to surface and subsurface knowledge concerning the Pennsylvanian deposits in the Mid-Continent region. Evidence of early Pennsylvanian diastrophism in southern Oklahoma, with attendant effects on sedimentation, has not long been known. Adequate description and interpretation of the remarkable Pennsylvanian section south of the Arbuckle Mountains has become available only within the past few years through the work of Goldston[1] and especially of Tomlinson.[2] Morgan[3] has worked out important overlap relations of the Boggy and other formations north of the Arbuckle Mountains, and has obtained valuable paleontologic information concerning the Pennsylvanian in this district. The completion of an accurate, detailed geological map of Oklahoma by Miser[4] is a most useful

[1]W. L. Goldston, "Differentiation and Structure of the Glenn Formation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 6 (1924), pp. 5-23.

[2]C. W. Tomlinson, "The Pennsylvanian of the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), 79 pp.

[3]G. D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Oklahoma Bur. Geol. Bull. 2* (1924), 248 pp.

[4]H. D. Miser, *Geologic Map of Oklahoma, 1:500,000*, U. S. Geol. Survey (1926).

contribution. A great deal of investigation of the microscopic faunas of the Pennsylvanian in north Texas and Oklahoma, with publications chiefly by Cushman and Waters, Harlton, and Roth, has been conducted during the last two or three years, but up to the present these researches have not been carried sufficiently far to make the studies definitely useful in inter-regional correlation. Considerable collections of megascopic and microscopic fossils have been made in Texas by Plummer and Moore, in the Ardmore basin by Girty and Roundy and by Moore, and in the area north of the Arbuckles chiefly by Girty and by Morgan. The writer, in company with Miser and others, has visited many of Morgan's localities and other places, collecting fossils. In the northern part of the Mid-Continent the paleontologic work of Beede and Rogers and of Girty is of basic importance.

The correlation of the Texas Pennsylvanian presented by Plummer and the writer[1] in 1921 is the first detailed attempt to recognize, in the strata south of Red River, equivalents of the better known formations in the north. This has furnished the essential basis of correlation tables involving the Texas Pennsylvanian published subsequently, except that of Morgan, which will be discussed later. The present paper, prepared in response to a request from the committee on the Pennsylvanian-Permian symposium at the Fort Worth meeting of the Association, is intended to present briefly the present status of the writer's studies on correlation in Texas and Oklahoma. Data in hand indicate the need of revision of correlations previously offered, but very much work remains to be done before many of the questions now before us can be solved.

BASIS OF CORRELATION

Among criteria which are useful in correlating the sedimentary deposits of different areas are: (1) continuity of beds, (2) lithologic character, (3) sequence of formations, (4) relations to structure and unconformities, and (5) paleontologic characters. It is not necessary or desirable to discuss these in detail.

Although in some cases actual *continuity of outcrops* does not necessarily indicate contemporaneity of deposits, most of the stratigraphic divisions of the Pennsylvanian in the Mid-Continent region that are traceable at the surface appear to mark deposits laid down in approximately the same unit of geologic time. The compilation of mapped outcrops of beds by Miser, in Oklahoma, is exceedingly useful as a basis of correlation of the Pennsylvanian strata north of the Arbuckle Mountains with exposures

[1] F. B. Plummer and R. C. Moore, "Stratigraphy of the Pennsylvanian Formations of North-Central Texas," *Univ. of Texas Bull. 2132* (1921), p. 212.

in the northern part of Oklahoma and Kansas. It should be noticed, however, that overlap, especially in a series of sandy and shaly beds where recognition of such overlap is difficult, may lead to very erroneous conclusions regarding correlation. In northern Texas it is possible to trace the more or less lenticular sandstones which replace Cisco limestones and shales northward to Red River and possibly into some of the territory in Oklahoma, but many of the beds which are mapped in the Ardmore basin can not be traced directly to the south. None of the Pennsylvanian strata north of the Arbuckles, except the Pontotoc, can be followed at the surface to the south side of the mountains, but it is possible that ultimately some beds may be traceable below the surface around the west end of the uplift.

As pointed out by Tomlinson,[1] the *lithologic character* of successive beds is often of greatest value in correlation. This is presumably most true as applied to a rather small territory, but there are many striking illustrations of extremely widespread occurrences of similar or identical lithologic characters marking deposits of a certain age. This has been found to be true in some degree of the Pennsylvanian rocks in the northern part of the Mid-Continent district, and the writer[2] has elsewhere discussed some of the factors probably responsible for these conditions. However, certain marked changes along the strike are known to occur in various districts, limestones grading laterally into shale and sandstone, and marine strata passing laterally into red beds. Considered broadly, the lithologic character of the Pennsylvanian rocks of Oklahoma and Texas bears definite relation to the varying conditions of marine invasion and to vertical movements of near-by lands, the active erosion of which at certain times supplied large volumes of coarse clastic material to the adjacent sea areas.

Like *sequences of beds* aid in establishment of equivalence of sedimentary deposits, especially in limited districts, but because of a certain rhythm or cycle in the sequence of lesser stratigraphic units there may be a misleading duplication of beds at different horizons. In so far as like conditions dependent on diastrophic movements or other broad conditioning factors are attained in different areas, these may be marked by like sequences of formation units, and recognition of the sequence aids in proper correlation of the deposits.

The correlative *significance of structure* is clear in southern Oklahoma, but in most of the area of Pennsylvanian sedimentation conditions were

[1] C. W. Tomlinson, *op. cit.*, pp. 66-69.

[2] "The Environment of Pennsylvanian Life in North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 459-87.

relatively stable, and the beds are essentially parallel from the bottom to the top of the section. Disconformities may be recognized locally, but their areal extent is often difficult to determine, and their time value a matter of doubt. The marked overlap at the base of the Boggy and certain other formations in southern Oklahoma, first pointed out by Morgan and subsequently shown by the extensive drilling in Seminole County and adjacent territory, and the unconformities and overlaps at the base of the Pontotoc are obviously significant in correlation. There is certainly a considerable time break between the youngest part of the highly deformed Hoxbar formation and the overlying sub-horizontal Pontotoc sediments.

The importance of *paleontologic evidence* in correlation is presumably too well understood by all geologists to call for detailed discussion. Most of the fossil invertebrates of the Pennsylvanian, however, are notoriously long ranging, and special problems are encountered in attempts to establish precise correlation of Pennsylvanian strata on the basis of their contained organic remains. In the light of present knowledge it is generally not only impossible to make reliable correlation of individual beds or formations in the Pennsylvanian sections of different regions on the basis of fossils alone, but there may even be uncertainty as to the relationship of certain larger stratigraphic divisions. Divergence of results in correlation based essentially on faunal evidence is illustrated by the previously published correlations of Morgan[1] and the writer for Texas and Oklahoma (Fig. 1). The writer placed chief reliance on the distribution of a relatively minor part of the faunas which appeared sufficiently distinctive and, in general, limited in vertical range to have value for correlative purposes. Such fossils are *Chaetetes* among the corals, *Prismopora* among the bryozoans, *Chonetes mesolobus* among the brachiopods, and so on. The great majority of species, in some cases variable or rather loosely defined, were deemed to have little value in correlation. Morgan's correlations, on the other hand, were based on a combined mean of the ranges of all the species found in each fauna. The chief result of this was to make the divisions of the southern Oklahoma section, with which Morgan was particularly working, seemingly equivalent to much younger portions of the Pennsylvanian on the north and south than indicated by the writer. The extent of the error in Morgan's method of paleontologic correlation of the southern Oklahoma and Kansas sections is indicated by the actual tracing of beds at the surface as represented on the Oklahoma and Kansas geological maps. The Belle City limestone, instead of representing a horizon in the lower part of the

[1] G. D. Morgan, *op. cit.*, p. 157.

Wabaunsee group, is found to occur at the horizon of beds in the Kansas City group (Fig. 2). Outcrops can not be traced from the southern Oklahoma district into north Texas, but presumably the same sort of inaccuracies prevail in applying this method to comparison of the Oklahoma and Texas faunas.

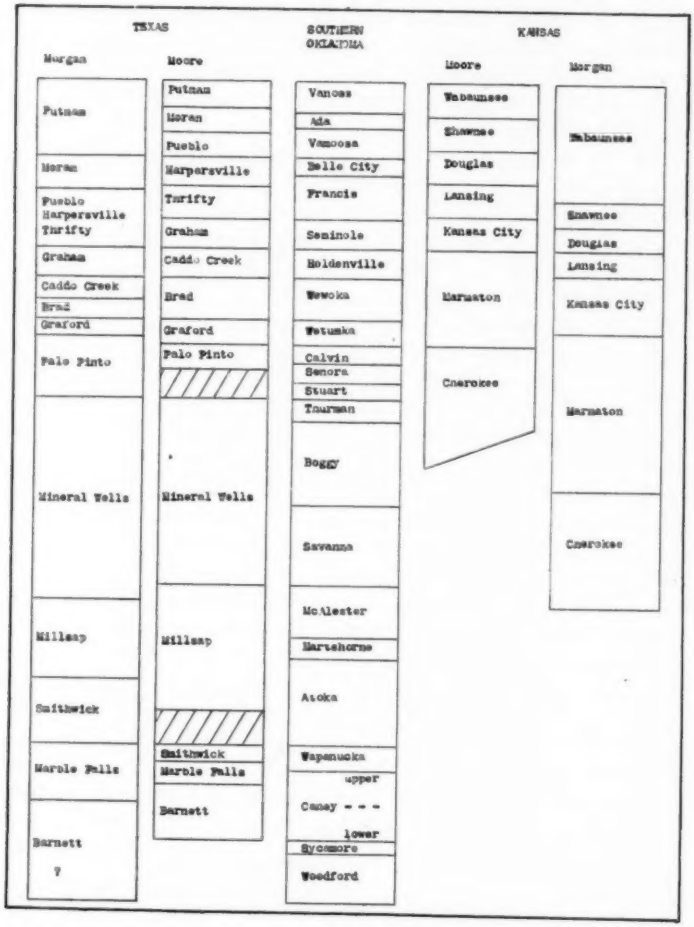


FIG. 1.—Correlation of the Texas, southern Oklahoma, and Kansas Pennsylvanian formations after Moore (1921) and Morgan (1924). The formations above the Seminole introduced by Morgan, were not differentiated in Moore's correlation.

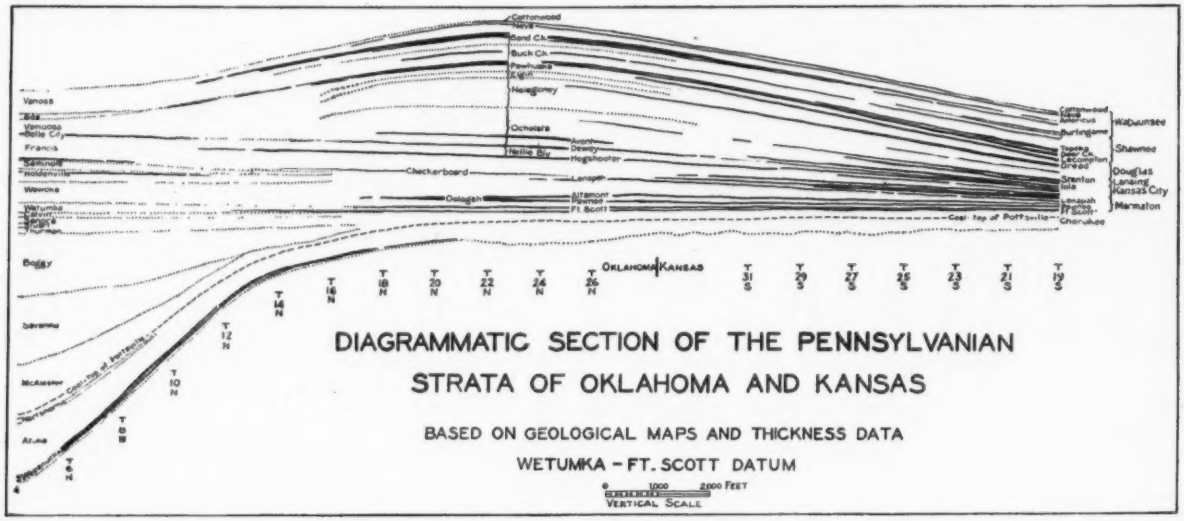

Cottonwood
Bond Ck.
Buck Ck.
Hoss
Ochelata
Nellie Bly
Checkerboard
Oologah
Vanoss
Vamoosa
Belle City
Francis
Senora
Hoodenville
Wewoka
Wetumka
Calvin
Holdenville
Hughes
Purdue
Boggy
Savanna
McAlester
Atoka
Avant
Dewey
Hogshooter
Lenapah
Altamont
Bartlesville
Ft Scott
Coal top of Pottsville
Cherokee
Oklahoma
Kansas
T 14 N
T 16 N
T 18 N
T 20 N
T 22 N
T 24 N
T 26 N
T 31 S
T 29 S
T 27 S
T 25 S
T 23 S
T 21 S
T 19 S
T 12 N
T 10 N
T 8 N
T 6 N
Cottonwood
Ochelata
Nellie Bly
Burlingame
Topeka
Deer Ck.
Lecompton
Oread
Stanton
Iola
Lenapah
Pleasanton
Cherokee
Wabaunsee
Shawnee
Douglas
Lansing
Kansas City
Marmaton
DIAGRAMMATIC SECTION OF THE PENNSYLVANIAN
STRATA OF OKLAHOMA AND KANSAS
BASED ON GEOLOGICAL MAPS AND THICKNESS DATA
WETUMKA - FT. SCOTT DATUM
0 1000 2000 FEET
VERTICAL SCALE

FIG. 2

Correlation on the basis of percentage of identical species distinguished in faunas from beds in different parts of the Pennsylvanian area is likewise misleading and useless. This may be surmised readily from the statement already made concerning the long range of most of the Pennsylvanian species. It is of course presumed that comparison of the faunas should be made from like sedimentary facies, for there may be noteworthy variations in the faunas of alternately succeeding limestones and shales. Even so, it commonly appears that the variation in the reported faunal composition of a certain bed or group of beds in one region may depend quite as much on incompleteness of collections and local variations in distribution due to undetermined causes as to other factors.

Since there is a very clearly determinable difference between the fossils of the lower, the middle, and the upper parts of the Pennsylvanian in at least a certain part of the fauna, it is possible that very careful study of some of the loosely defined long-ranging species may result in recognition of varieties or mutations that have definite stratigraphic significance. This is suggested by the recent work of Dunbar and Condra[1] on the fusulinids, and the writer's[2] study of certain large quantities of beautifully preserved bryozoan material shows the existence of numerous clearly defined species and varieties that have not previously been recognized.

It should be pointed out that within the restricted limits of an oil field or perhaps an area including several counties, very precise and detailed correlation of beds may be made on the basis of paleontologic characters, both megascopic and microscopic, or by either alone. Lithologic characters invariably afford valuable supplementary data. However, such correlation is empirical and is based almost altogether on detailed observation of the character and sequence of faunas in an established type section within the area. Such a section may be of little use in comparing the successive faunas of distant parts of the Pennsylvanian areas.

In short, paleontologic evidence must be used cautiously and intelligently in seeking to correlate widely separated parts of the Pennsylvanian deposits in North America. Perhaps the categorically positive conclusions which in many cases are demanded of paleontologists in oil company employ, encourage the making of unwarrantedly definite identification and correlation of parts of the Pennsylvanian in widely

[1]C. O. Dunbar and G. E. Condra, "Fusulinidae of the Pennsylvanian of Nebraska," *Nebraska Geol. Survey (2) Bull.* 2 (1928).

[2]R. C. Moore, "A Bryozoan Faunule from the Graham Formation, Pennsylvanian, of North Central Texas, *Jour. Paleont.*, Vol. 3 (1929), pp. 11-29, 121-156.

separated areas. Or perhaps certain of these workers have discovered altogether reliable but as yet unpublished paleontologic criteria for these correlations. Notwithstanding fairly detailed knowledge of these faunas, the writer is at present compelled to confess uncertainty and doubt in identification and inter-regional correlation of some Pennsylvanian strata purely on faunal grounds. It is believed that the possibilities of precise paleontologic work will be greatly increased when critical research on the Pennsylvanian faunas has been considerably extended. Accordingly, it should be re-emphasized that conclusions as to correlation of the Texas and Oklahoma sections based on fossil evidence are, in the main, to be regarded as tentative.

EVIDENCE OF PHYSICAL CHARACTERS

Continuity of beds.—Correlation of the sections in southern Oklahoma north of the Arbuckle Mountains, and in the central and northern part of the state, with the standard section of Kansas and Missouri, is properly included in a study of the relations of the Pennsylvanian beds of Oklahoma and Texas. The conditions of sedimentation extending northward from the mountain areas are presumably comparable with, and analogous to, conditions on the south side of these mountains in northern Texas. The historical geology of the two areas probably follows the same essential lines. Further, as very much of the detailed paleontologic information concerning the Pennsylvanian in the northern Mid-Continent area is derived from Kansas and Missouri, it is important to recognize the correlative stratigraphic units in Oklahoma.

Very considerable advances in knowledge concerning the stratigraphy of Oklahoma have been achieved through the work of petroleum geologists. These, together with other information, are largely made available through the excellent geological map compiled by Miser, by publications of the Oklahoma Geological Survey, and by papers appearing in this *Bulletin*. Since the Pennsylvanian rocks are for the most part gently inclined westward, the outcrops as represented on the map constitute in reality a stratigraphic cross section of these strata. It is true that the section is very obliquely inclined to the planes of stratification, but this does not greatly lower its value as an indication of stratigraphic relations. In diagrammatic form this section is presented in Figure 2, combined with representation of the approximate thickness of formations at certain defined points. The diagram, constructed on the Fort Scott-Wetumka as a datum, shows that the beds below this horizon, more than 5,000 feet thick in Morgan's Stonewall section, converge rapidly north-

ward, so that in northeastern Oklahoma and southeastern Kansas the equivalent Cherokee formation is 500 feet or less. If, as indicated by White,[1] the Hartshorne coal at the summit of the Hartshorne sandstone marks the base of the Allegheny, this horizon can be traced northward into the upper part of the Cherokee shale, at the horizon of the Bevier coal, approximately 100 feet below the top of the formation.[2] Although rather thin in the Stonewall quadrangle, the Pennsylvanian beds (Atoka and Hartshorne) below the Hartshorne coal are not less than 7,000 feet thick farther east.

The Wewoka, Holdenville, and Seminole formations are traced northward as far as Township 16 North. The Checkerboard and Hogshooter limestones just above the horizon of the Seminole are traced southward to Township 12 North or beyond, and are evidently equivalent to parts of the Francis formation. The Belle City limestone lies at the horizon of the Dewey limestone and may be more or less exactly equivalent to it. The Ochelata, Nelagoney, Elgin, and Pawhuska formations of north-central Oklahoma are mapped from the Kansas-Oklahoma boundary southward to Township 15 North, and are in part represented in the section north of the Arbuckles by the Vamoosa formation. There is certainly a considerable hiatus and overlap of the beds in the more southerly area, the coarse conglomerates of the Vamoosa probably representing only a small part of the finer clastics in northern Oklahoma. The higher Pennsylvanian formations contain limestones that are traceable much farther southward and appear to be represented, with hiatus and overlap, by the Vanoss formation comprising the lower part of the Pontotoc group.

The Kansas equivalents of the northern Oklahoma formations are indicated by the diagram. Projected field studies in southern Kansas and northern Oklahoma will undoubtedly make possible a precise correlation of the Pennsylvanian rocks of these regions.

Lithologic characters.—The Stonewall quadrangle section in southern Oklahoma shows above the limestone and black shale (Wapanucka and Upper Caney), at the base of the Pennsylvanian, a thick series of sandy shale and sandstone with some chert conglomerates and a few thin limestones in the Holdenville, Francis, and Belle City. The top of the section is largely made up of conglomerates, the Vamoosa and Ada

[1]David White, in A. J. Collier's "The Arkansas Coal Fields," *U. S. Geol. Survey Bull. 326* (1907), p. 24.

[2]David White, "Pottsville-Allegheny Boundary in the Interior Province," *Bull. Geol. Soc. Amer.*, Vol. 24 (1913), p. 716; "Notes on the Fossil Floras of the Pennsylvanian in Missouri," *Missouri Bur. Geol. and Mines* (2), Vol. 13 (1915), p. 262.

largely of chert and limestone, the Vanoss including felspathic material (Fig. 3).

In northern Oklahoma the sandstone and shale of the Cherokee is succeeded by a zone of rather prominent limestones, Fort Scott to Altamont inclusive, followed by shale, sandstone, and thin limestone beds, the sandstone predominating in the upper part of the section up to the base of the Pawhuska formation; the upper part of the Pennsylvanian consists largely of interbedded limestone, shale, and thin sandstone beds, with the limestone again relatively prominent.

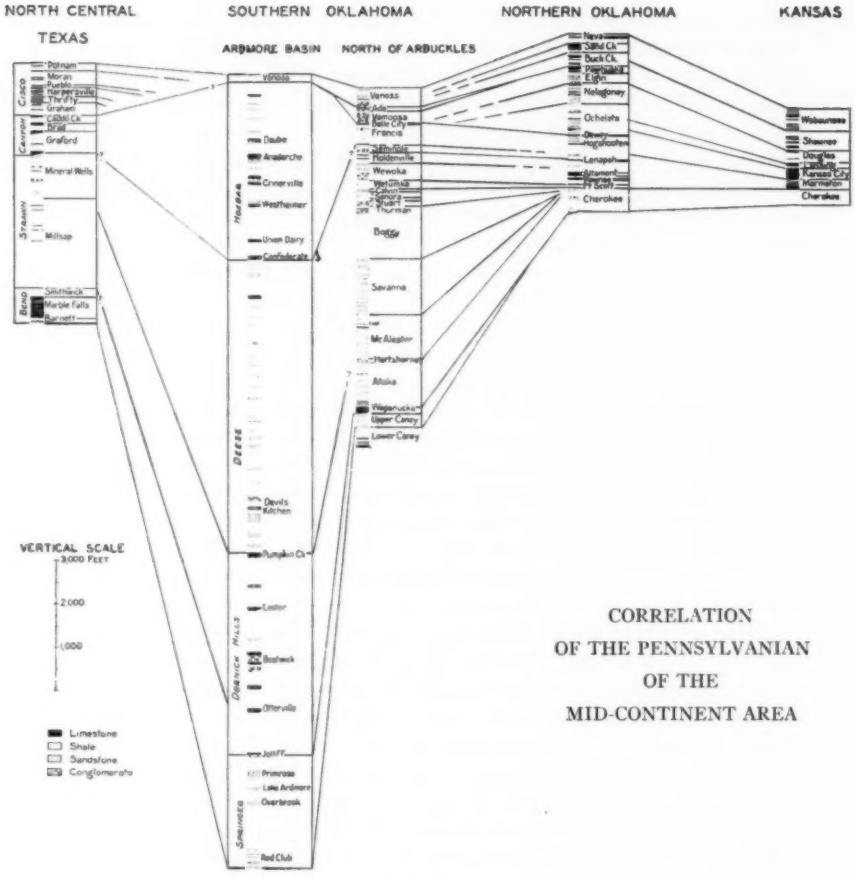
Excepting the Cherokee, the Kansas section is chiefly noteworthy on account of the prominence of its limestone, but relatively thick shale and sandstone appear in the upper Marmaton, lower Douglas, upper Shawnee, and lower Wabaunsee.

The very thick Pennsylvanian section of the Ardmore basin described by Tomlinson[1] consists mostly of shale, more or less sandy, numerous sandstones, a few conglomerates, and in the lower middle and upper parts, beds of limestone. Observations of lithologic character indicate rapid sedimentation accompanied by profound subsidence. Nevertheless, there appears to be more limestone in the aggregate than is found in the section on the north side of the Arbuckle Mountains.

The section of northern Texas is divisible on a lithologic basis into parts that correspond closely with the group divisions: Bend, mainly limestone; Strawn, sandstone, shale, and conglomerates; Canyon, prominent limestones interbedded with shale; and Cisco, thin limestones with considerable sand, shale, and some conglomerates. Most rapid sedimentation apparently occurred in Strawn time.

Sequence of beds.—As the lithologic character of the Pennsylvanian strata and the sequence of different kinds of deposits probably correspond, as has been indicated, with broad movements in the sea and near-by lands, we may anticipate a certain correspondence in the various sections described of the character and order of the main stratigraphic units. Thus we are prepared to recognize as possibly corresponding units, (1) the limestones at the base of the Texas and southern Oklahoma sections, followed by (2) the thick clastic deposits of the Strawn, Deese, and possibly upper Dornick Hills and the thick sands and shales above the Wapanucka limestone north of the Arbuckles. Question is properly raised as to the upper limit of the latter division and it may be noted here simply that (3) limestones succeed the sands and shale in each of these areas. In northern Oklahoma the basal limy zone (Morrow) gradually dis-

[1] C. W. Tomlinson, *op. cit.*



CORRELATION
OF THE PENNSYLVANIAN
OF THE
MID-CONTINENT AREA

FIG. 3

appears, succeeding sandstone and shale (Cherokee) is not very thick, and, following a zone of limestones (Fort Scott-Altamont), there are very prominent sands (Ochelata-Nelagoney-Elgin) which are followed by a second dominantly limy zone. These sequences are significant, as they are related to changes in conditions of sedimentation that are regional in character.

Structure and unconformities.—As has been indicated, the profound deformation of parts of the Pennsylvanian deposits and the occurrence of considerable hiatuses in the sections near the mountains are importantly involved in the geologic history and in the problem of correlation of the Pennsylvanian strata in this general region. The great unconformity between the Vanoss and the underlying Hoxbar clearly may represent a considerable part of the upper Pennsylvanian in other areas. However, there is no known evidence of deformation that affected parts of the Pennsylvanian in areas distant from the mountain region, in such a way that these parts can be recognized as older than sediments laid down subsequent to time of diastrophism.

PALEONTOLOGIC EVIDENCE

A detailed comparison of the known faunas of the Pennsylvanian of Texas and Oklahoma, together with equivalents in Kansas and Missouri, would extend this paper unduly. For the present, 95 per cent or more of the faunas may be passed over as having more or less indeterminate value in correlation. We will undertake simply to indicate certain tie points and some of the most important faunal relations.

Perhaps the most distinctive assemblage of Pennsylvanian fossils, as regards identification of a stratigraphic group, is that of the beds of Morrow (Pottsville) age. These are represented in southern Oklahoma north of the mountains by the Wapanucka limestone and possibly by the shale and sandstone of the underlying Caney; and in the area south of the Arbuckles, by the Springer and part of the Dornick Hills (especially Otterville and Jolliff limestones). In Texas they are equivalent to the Bend group, possibly excepting the Barnett shale. The post-Morrow Pottsville, comprising the lower part of the Winslow formation, Atoka formation, upper Dornick Hills and possibly a part of the Deese, and the Millsap formation, contains many of the distinctive faunal elements of the Morrow, but lacks others. This early Pennsylvanian fauna is marked by the occurrence of *Michelinia*, *Archimedes*, *Prismopora*, *Glyptopora*, *Chonetes choteauensis*, *Productus morrowensis*, *Spirifer rockymontanus*, *Hustedia miseri*, *H. brentwoodensis*, a variety of mollusks including

several cephalopods and other fossils. In addition to the Morrow species cited, Girty and Roundy[1] report from the Dornick Hills the following Pottsville species: *Nucula subrotundata*, *N. elongata*, *Leda inflata*, *Anthraconeilo kessleriana*, *Myalina orthonota*, *Solenomya sharonensis*, and *Schizophoria* aff. *resupinoides*. The general equivalence of the beds containing these organisms at the base of the Pennsylvanian sections of Texas and Oklahoma is clear. There is doubt, however, as to exact relationships of stratigraphic subdivisions in the respective areas. The top of the Smithwick shale, for instance, can not now be recognized definitely in the southern Oklahoma section. Combining other lines of evidence with paleontologic testimony, it is probable that the Millsap and Bend correspond to the Dornick Hills and Springer and to the beds below the McAlester formation. Supporting paleobotanic evidence reported by David White[2] is found in the plants at the horizon of the Thurber coal at the top of the Millsap formation, which is identified as basal Allegheny, corresponding to the coal at the base of the McAlester formation.

One of the most important fossils from the standpoint of stratigraphic correlation in the lower Pennsylvanian is *Chonetes mesolobus* N. and P. and its varieties. In Kansas and Missouri the zone of *Chonetes mesolobus* comprises the Cherokee and Marmaton formations, and in Oklahoma it is found in equivalent strata ranging upward in the section north of the Arbuckles to the Holdenville shale. In the Ardmore basin the zone of *Chonetes mesolobus* comprises the Deese and the upper part of the Dornick Hills formation. In Texas this species has been obtained by the writer only from the Mineral Wells formation. Associated with *Chonetes mesolobus*, and of nearly equal value in correlation, are the coral *Chaetetes milleporaceus*, the brachiopods *Marginifera muricata*, *Pugnax rockymontanus*, and *Spirifer rockymontanus*, the protozoan *Fusulinella meeki*, and the bryozoan *Prismopora*. Various other species such as the gastropods *Trachydomia wheeleri* and *Zygopleura multicostata* are rather common here and rare or absent in higher beds. Altogether this faunal zone is fairly definite and distinctive. On combined physical and organic bases its upper limit may be approximately defined as the top of the Marmaton, the horizon of the Checkerboard limestone, the top of the Seminole formation, and the top of the Deese. In north Texas the top of this faunal zone should probably be placed at the base of the

[1]G. H. Girty and P. V. Roundy, "Notes on the Glenn Formation of Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 331-47.

[2]Personal communication.

Canyon, although evidence for this correlation is at present not at all definite. One record of *Chaetetes milleporaceus* in the Graford formation and the occurrence in the lower Canyon of *Pugnax rockymontanus*, *Trachydomia wheeleri* and some other species suggest the *Chonetes mesolobus* zone rather than higher strata. However, since both the latter species are known to occur, though sparingly, in upper Pennsylvanian rocks, the presence in the Graford of ammonites of Cisco type and many other late Pennsylvanian forms favors correlation of the Canyon with post-Marmaton beds. It may be noted here that *Productus insinuatus* and *Enteletes hemiplicata*, which in Kansas and Missouri are reported only in post-Marmaton beds, *Enteletes* first appearing in the upper Lansing, are recorded from the Holdenville formation in southern Oklahoma. Nevertheless, on the basis of continuity of beds, the Holdenville appears to be no higher than the horizon of the Lenapah.

Faunal divisions of the Pennsylvanian above the Marmaton are neither very distinctive nor clearly defined, although at certain horizons new species are recorded and old forms seem to drop out. The so-called formations, or, as they perhaps should better be termed, groups, Kansas City, Lansing, Douglas, Shawnee, and Wabaunsee, are not altogether well defined, natural stratigraphic divisions. They can be traced southward across Kansas and their equivalents determined in the section of northern Oklahoma. Most of the Coffeyville formation and the lower Ochelata, possibly to the top of the Avant limestone, appears to be of Kansas City age, and according to the map the lower part of this zone is represented in the Francis and Belle City formations. Above the latter and possibly within the formation designated Vamoosa, there is evidently a hiatus representing the upper Kansas City, Lansing, Douglas, and possibly a part of the Shawnee, for it is probable that the coarse sediments of the Vamoosa near the Arbuckle Mountains represent the upper (perhaps mainly the Elgin) rather than the middle or lower parts of the sand section in northern Oklahoma and southern Kansas above the horizon of the middle Kansas City.

The Shawnee and Wabaunsee groups are represented by the beds in northern Oklahoma above the Nelagoney, and the feldspar-bearing beds of the Pontotoc correspond to beds above the Pawhuska limestone. There are almost certainly disconformities and overlaps in this part of the Pennsylvanian section north of the Arbuckles.

In the Ardmore basin the Hoxbar formation, with a maximum thickness of approximately 4,000 feet, is tentatively correlated with the post-Marmaton beds north of the mountains, that is, Francis, Belle City, and

possibly several formations corresponding to the hiatus above the Belle City which are represented farther north in Oklahoma. The fossils reported from the Hoxbar are not very definitely diagnostic, but forms that are characteristic of the lower Pennsylvanian seem to be absent, and comparison of the species that do not have too extended a range distinctly implies an age that is Kansas City or younger (see Table I). In addition to the fossil collections reported by Girty and Roundy, the writer has considerable collections which he has made in company with C. W. Tomlinson.

Prior to deposition of the red feldspathic Vanoss, the older Pennsylvanian in the Ardmore basin was extensively folded and locally faulted, and was bevelled by erosion. There is, therefore, a hiatus between the Hoxbar and Vanoss that probably includes the Ada and Vamoosa north of the mountains and an undetermined part of the Wabaunsee, Shawnee, Douglas, and possibly older divisions of the Kansas section.

In north Texas the Hoxbar is tentatively correlated with the Canyon and the Vanoss with a part, probably the upper part, of the Cisco, in which there are important beds of sandstone and conglomerates and, at least in the north, some feldspathic members. The hiatus at the base of the Vanoss possibly represents an upper part of the Canyon group and in all probability includes the lower Cisco.

In the correlation of the Texas with the Oklahoma-Kansas section published by Plummer and the writer[1] in 1921, similarity of the beautifully preserved faunas in the upper part of the Graham with those described from the Wewoka and in the Kansas City beds was emphasized, the Graham being regarded as approximately equivalent to the Kansas City group. A re-study of all the data, physical as well as faunal, suggests that the Canyon is probably more nearly equivalent to the Kansas City and possibly the Lansing, and that the Cisco corresponds more nearly with Douglas, Shawnee, and Wabaunsee. Reliable correlation of the subdivisions of these respective sections is not at present possible, though there is a suggested correspondence in physical and faunal characters of the sandy lower Cisco, including the Graham, with the Douglas beds, the middle limy zone, including Thrifty, Harpersville, and Pueblo, with the Shawnee, and the higher Texas division with the Wabaunsee. Such correlation is, however, very tentative.

In their study of the Pennsylvanian fusulinids of the Mid-Continent region, Dunbar and Condra have distinguished the species *Triticites cullomensis*, which in Kansas and Nebraska ranges from the Lecompton to Emporia limestones (Shawnee-lower Wabaunsee), and is recorded also

[1] F. B. Plummer and R. C. Moore, *op. cit.*, p. 212.

TABLE I

TABLE I

FOSSILS FROM THE PENNSYLVANIAN OF THE ARDMORE BASIN

Texas												*Ardmore Basin, Oklahoma*	*Northern Oklahoma, Kansas, Missouri*							
Bend	*Millsap*	*Mineral Wells*	*Graford*	*Brad*	*Caddo Creek*	*Graham*	*Thrifty*	*Harpersville*	*Pueblo*	*Moran*	*Putnam*	*Hoxbar Fossils*	*Morrow*	*Cherokee*	*Marmaton*	*Kansas City*	*Lansing*	*Douglas*	*Shawnee*	*Wabaunsee*	*Permian*
			M*									*Productus insinuatus*					G				
												Isogramma millepunctata				B		B		BG	
			cf			cf						*Pseudomonotis equistriata*				B	G	G	B	B	B
			?	D							M	*Deltopecten occidentalis*			G	BG	BG	BG	B	B	BG
			M	M		M		M	M			*Myalina subquadrata*			B	B	B	B	G	B	
								?	M			*Myalina kansasensis*				B		G	BG	B	B
			M			M						*Edmondia aspenwallensis*			?B	B			B	B	B
			M			M	D	M	M		M	*Pinna peracuta*				BG		B	B	B	B
		?										*Schizodus affinis*					G				
									cf			*Chaenomya cooperi*						?B			?B
			D	D		D						*Euphemus nodocarinatus*				G					
		M	M									*Goniospira lasallensis*					G	G			
												Naticopsis scintilla				G					
			M									*Trachydomia wheeleri*		G		B			BG		
												Deese Fossils									
M												*Prismopora*		B	BG						
		M										*Chonetes mesolobus*		BG	BG						
M	M	M										*Spirifer rockymontanus*	X	G							
												Dornick Hills Fossils									
sp												*Prismopora serrata*									
sp												*Prismopora concava*	X								
sp												*Cystodictya aff. brentwoodensis*	X								
?			D									*Michelinea eugeneae*†	X								
M			M									*Chaetetes milleporaceus*‡		BG	BG						
		M										*Chonetes mesolobus*		BG							
M	M	M										*Spirifer rockymontanus*	X	G							
sp												*Hustedia brentwoodensis*	X								
	M											*Marginifera muricata*		BG	BG						
			cf			cf						*Pseudomonotis equistriata*				B	G	G	B	B	B
cf												*Paralegoceras iowense*									
												Anthraconeilo kessleriana	X								
												Myalina orthonota	X								

*B, reported by Beede and Rogers; G, Girty; D, Drake; M, Moore; X, Mather.
†In Moore's collections from Anadarche limestone.
‡Reported by Goldston.

from the Jacksboro limestone (lower Cisco), and *T. plummeri*, which occurs in the Oread and Deer Creek limestone (upper Douglas-lower Shawnee), and is found in Texas in the South Bend shale, Breckenridge limestone, and Jacksboro limestone (Cisco). The upper Cisco and the Wabaunsee are characterized by general absence of fossil corals and by the absence of many species common in lower beds. In Texas, Oklahoma, and Kansas the appearance of limestones largely made up of fusulinids essentially begins in the lower Cisco and upper Douglas, respectively.

SUMMARY

The accompanying chart (Fig. 3) represents the writer's tentative correlation of the Pennsylvanian in Texas, Oklahoma, and Kansas. It is based on consideration of all the available data, but is subject to revision particularly as comparative study of the faunas shows species or varieties that can be used for more definite correlation

It is evident that in the early part of Pennsylvanian time (Morrow-Bend) seas were more or less clear and adjacent lands presumably low-lying. This was a time in which limestone was spread widely, associated with more or less black shale and locally some sandstone. Mountain-making uplifts involved the Criner Hills and other buried ranges south of the Arbuckles, and probably most of the Wichita chain after early Dornick Hills and Wapanucka times,[1] the local limestone conglomerates and the thick shale and sandstone of the succeeding beds showing effects of active erosion in near-by land areas. Recurrence of movements possibly involving only parts of the mountain area are indicated by overlaps, such as are shown by Morgan[2] at the base of the McAlester, Boggy, and Wewoka and by the coarse conglomerates that were deposited in these and other formations north of the Arbuckles, in the Deese, and in the Mineral Wells formation. Pre-Marmaton sandstones and shales were spread very far northward, but in diminishing thickness. In the latter part of this epoch (Marmaton), limestone began to be laid down in the north, but further spreading of sands and muds before Kansas City time

[1]C. W. Tomlinson (*op. cit.*, p. 21) dates this orogeny "at or shortly before the beginning of Dornick Hills time." The lower Dornick Hills, including the Otterville and Jolliff limestones, and comprising approximately 1,000 feet of strata, was laid down in quiet conditions and it appears to correspond in age with the widespread epoch of limestone deposition in Bend and Morrow time. The first appearance of conglomerates, as noted by Tomlinson, is in the Bostwick member of the Dornick Hills, 1,200 to 1,500 feet above the base of the formation. It seems to the writer that the folding which is clearly indicated by structural as well as lithologic evidence should be regarded as having been initiated in mid-Dornick Hills time rather than earlier.

[2]G. D. Morgan, *op. cit.*

is shown by the conglomerates of the Wewoka and Seminole and the sandy beds of the Pleasanton.

In Kansas City time limestones were laid down throughout much of the Mid-Continent area, but in the vicinity of the southern Oklahoma mountains sedimentation was evidently very rapid, and the limestones are quantitatively much less important than clastic sediments.

The chief epoch of mountain-making in the Arbuckle region is subsequent to Hoxbar and Belle City time. Above these formations is a great hiatus, and effects of active erosion of the uplifted areas seem to be indicated in the invasion of clastic materials in the lower Cisco of Texas and in the thick sands of post-Kansas City age in northern Oklahoma. In later Pennsylvanian time, and apparently without interruption into lower Permian time, there were widespread, frequently recurring limestone-forming conditions, which in the north and the south temporarily became dominant. In the vicinity of the mountains sedimentation was mainly subaerial, the red continental sediments grading laterally northward and southward into marine beds. The chief epochs of mountain-building are thus dated after the Morrow-Bend and after the Kansas City-Canyon.

CORRELATION OF PENNSYLVANIAN-PERMIAN OF GLASS MOUNTAINS AND DELAWARE MOUNTAINS[1]

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ABSTRACT

The formations of the Glass Mountains are correlated, not only with those of the Delaware sandstones, but also with those of the Shafter, Texas, region and the Sierra Diablo and the Hueco Mountains.

A correlation of formations of regions in which very little detail work has been done is necessarily only tentative. It is very desirable that careful measurement and description of each layer, together with careful collecting of fossils, be made in both of these regions, and until this is done no exact correlation can be made.

Udden,[3] Beede,[4] and Schuchert[5] have published correlation tables including these regions. As a result of several months of study of the region from the Glass Mountains west to El Paso, Texas, the writer has formed opinions, in some respects, different from those of these authors (Fig. 1).

In the Glass Mountains the earliest formations of the Pennsylvanian, the Tesnus, Dimple, and Haymond, have been placed below the Canyon, since they are more highly metamorphosed than the overlying Gaptank, which is Canyon. The fossil evidence is not complete enough to correlate them with any other formations. The Gaptank of Udden, or lower Gaptank of Keyte, Blanchard, and Baldwin[6] is without question Canyon and may be correlated with the Magdalena of the Sierra Diablo and Hueco mountain regions. In the same paper Keyte, Blanchard, and Baldwin regarded the upper Gaptank as Cisco. This opinion was based on the fauna exclusive of the ammonoids. Since that time, J. P. Smith[7]

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, March 9, 1929.

[2]Colorado College.

[3]*Univ. of Texas Bull. 44.*

[4]*Univ. of Texas Bull. 1852.*

[5]*Amer. Jour. Sci.*, Vol. 14.

[6]*Jour. Paleont.*, Vol. 1, No. 2.

[7]*Amer. Jour. Sci.*, Vol. 17.

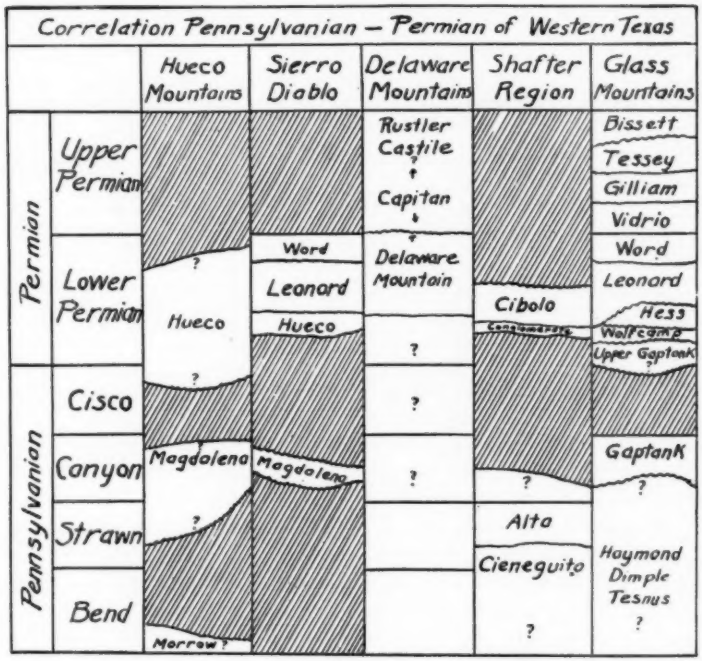

FIG. 1

has determined these ammonoids to be earliest Permian. Smith states: "The ammonoid fauna discussed in this paper shows that the so-called upper Gaptank is transitional to Permian and is of Wolfcamp age." The writer does not agree with the last part of this statement as there is an erosional unconformity between the "Zone of *Uddenites*" and the true Wolfcamp. The fauna is very different, the Wolfcamp containing practically no Cisco fossils, but a fauna similar to that of the basal conglomerates of the Cibolo and of the middle Hueco. The term Hueco as used in this paper refers to all of the Carboniferous in the Hueco Mountains above the Magdalena.

The "Zone of *Schwagerina*" occurs in the Wolfcamp; in the Hueco at the base of Victorio Peak, north of Van Horn, Texas; 2,000 feet above the base of the Hueco, near the top of South Helm Peak, Hueco Mountains; at the base of North Helm Peak; and in the Little Hatchet Mountains, southwest New Mexico, where it occurs approximately 600 feet

above the top of the Abo red beds. At each of these localities both *Schwagerina uddeni* and *S. fusilinoides* are plentiful.

It is generally agreed that the Leonard and Word of the Glass Mountains are equivalent, in part at least, to the Delaware Mountain formation. Girty[1] lists the following species from both Delaware Mountain limestone and the Leonard: *Fusulina elongata, Guadalupia zitteliana, Cystothalamia permiana, Cladopora spinulata, Domopora? constricta, Acanthocladia guadalupensis, Orthotetes distortus, Leptodus americanus, Richthofenia permiana, Productus meekanus, Camarophoria venusta, Squamularia guadalupensis, Hustedia meekana, H. papillata, H. bipartita, Parallelodon multistriatus, Aviculopecten sublaqueatus,* and *Astartella nasuta.* Schuchert[2] has identified the following from the Leonard that Girty recognized from the Delaware Mountain: *Meekella multilirata, Pugnax swalloviana, Notothyris schucherti, Productus guadalupensis, Productus subhorridus* var. *rugatulus, Aulosteges americanus,* and *Productus occidentalis.*

Beede[3] identified Word ammonoids from the Sierra Diablo Mountains and separated the Delaware Mountain limestone into the Leonard and Word.[4]

The Vidrio, Gilliam, Tessey, and Bisset of the Glass Mountains are probably equivalent, at least in part, to the Capitan, Castile gypsum, and Rustler, but as yet no fossil evidence has been reported to substantiate this correlation; hence, the correlation of the upper Permian of the two regions will necessitate further investigation.

In the Shafter region the Cibolo fauna is practically identical with that of the lower Leonard, with the exception of the basal conglomerate from which Weller[5] described several Permian crinoids. *Delocrinus major,* one of Weller's species from the base of the Cibolo, is found in the Wolfcamp in the Glass Mountains approximately 15 feet below the "Zone of *Schwagerina.*"

The fauna of the Cieneguita and Alta is so meager, that like that of the Tesnus, Dimple, and Haymond, little is known except that it is Pennsylvanian.

In the Hueco Mountains the Helms (Chester) is overlain by approximately 150 feet of Pennsylvanian that Girty regarded as Morrow. An

[1] *U. S. Geol. Survey Prof. Paper 56.*

[2] *Op. cit.*

[3] Personal communication.

[4] *Univ. of Texas Bull. 1852.*

[5] *Jour. Geol.,* Vol. 17.

angular unconformity exists between this and the Magdalena. The Hueco is represented by more than 3,000 feet of strata, and, although it is separated from the Magdalena by an angular unconformity, there is a possibility that the lower part is Pennsylvanian.

STRATIGRAPHY OF OUTCROPPING CARBONIFEROUS AND PERMIAN ROCKS OF TRANS-PECOS TEXAS[1]

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ABSTRACT

The later Paleozoic systems are exposed in several disconnected areas in trans-Pecos Texas, including the Marathon region, the Delaware-Guadalupe Mountains, and the Diablo Plateau. The Carboniferous of the Marathon Basin is nearly 8,000 feet in thickness and consists mostly of clastic sediments. On the northwest these give place to limestones, which are best exposed in the Hueco Mountains, where they are about 2,000 feet thick. These beds are separated from the overlying Permian in all of trans-Pecos Texas by a notable structural unconformity. In the Glass Mountains and Delaware-Guadalupe Mountains the Permian is represented by normal marine deposits whose rich and varied faunas refute the common notion of a general impoverishment of Permian life. These pass laterally into rocks of different facies, including limestones bearing poor faunas, and deposits of red beds, salt, and anhydrite.

INTRODUCTION

Carboniferous and Permian rocks are, in general, buried beneath the Cretaceous in trans-Pecos Texas and crop out only in isolated uplifts of large and small size. Because of the disconnected nature of the exposures and the great facies variations, correlations must depend very largely on fossils. The most important outcropping areas are in the Marathon region, in the Delaware-Guadalupe Mountains, and in the Diablo and Hueco mountains and the intervening Diablo Plateau (Fig. 1). The Permian forms the widest outcropping areas, embracing large areas which have previously been mapped as Pennsylvanian.

It is the purpose of this paper to describe briefly the nature of these outcropping rocks and to suggest their probable correlation, both within the trans-Pecos province and with other regions. It is based on four summers' field work in the area, and on an extensive study of the Permian faunas now in progress by the junior writer. The limits of this paper make it impracticable to set forth the details of evidence upon which the conclusions are based, and for these the reader is referred to forthcoming bulletins of the Bureau of Economic Geology.

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Revised manuscript received by the editor, May 30, 1929. Published by permission of the director of the Bureau of Economic Geology, University of Texas, Austin, Texas.

[2]Peabody Museum.

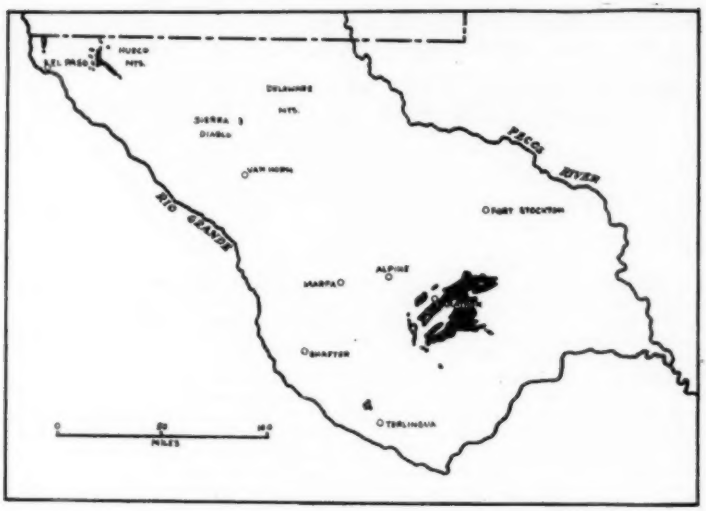

FIG. 1.—Map of trans-Pecos Texas, to show area of outcrop of Carboniferous rocks (in black).

CARBONIFEROUS ROCKS

Carboniferous outcrops are limited in extent; they are present in the areas of folded rocks of the Marathon Basin and the Solitario, and also in the Hueco and Franklin mountains. There is a small outcrop near the mouth of Marble Canyon, at the foot of Sierra Diablo.[1]

The Carboniferous of the Marathon Basin is a great clastic group, nearly 8,000 feet in thickness (Fig. 2). At the base is the Tesnus shale and sandstone (3,000 feet), overlain by the Dimple limestone (1,000 feet), the Haymond shale and sandstone (approximately 2,000 feet), and the Gaptank shale and sandstone, containing beds of limestone and conglomerate (1,800 feet). The clastics of the Tesnus and Haymond are shown by microscopic studies to have been derived from crystalline and metamorphic rocks probably of the old borderland of Llanoris, on the southeast. The conglomerates of the Gaptank show that most of its sediments were derived from the Paleozoic beds of the geosyncline, for they contain fragments of all the older formations, but particularly of the Dimple limestone and Caballos novaculite. The conglomerates

[1]The Cienaguita and Alta beds of the Shafter region, formerly classed as Pennsylvanian, have been proved to be of Leonard (Permian) age.

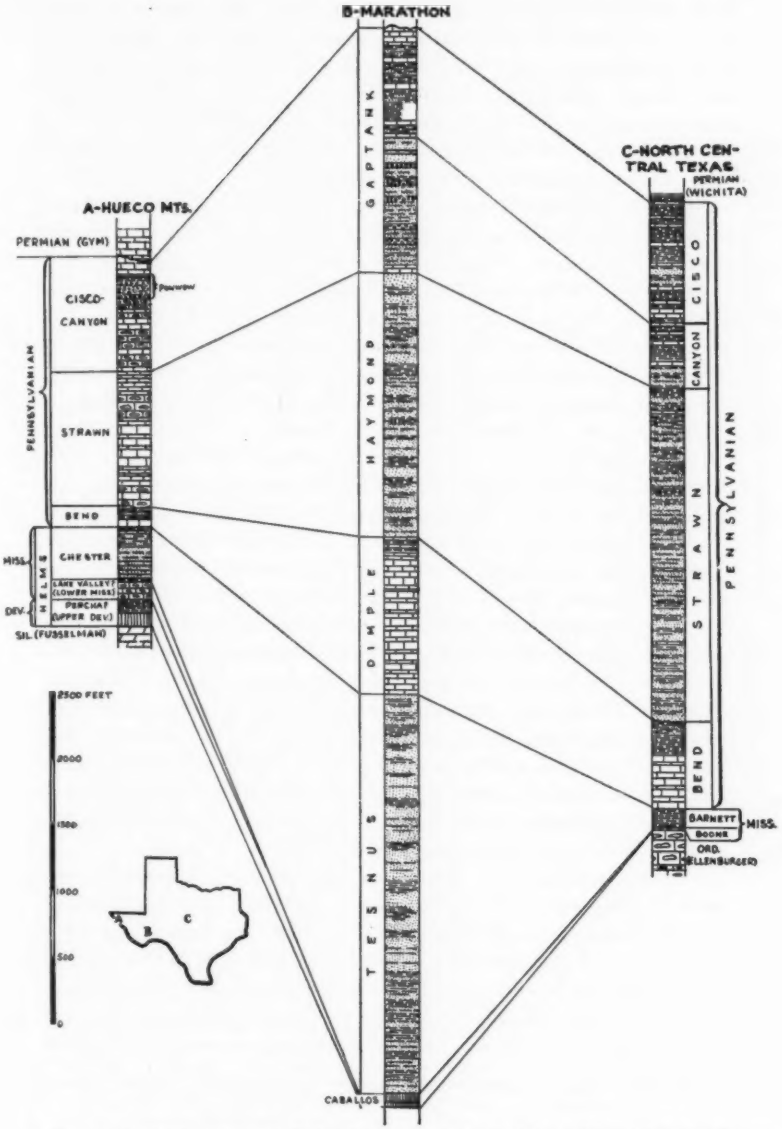

FIG. 2.—Vertical sections of Carboniferous strata in the Hueco Mountains, the Marathon region, and north-central Texas, and their suggested correlation.

show that the mountain-making of the Caballos disturbance began as early as middle lower Gaptank time, though it culminated at the end of the Carboniferous. Only the Gaptank formation contains plentiful fossils; these indicate a correlation with the Canyon and Cisco groups of central Texas. The formations below have yielded no guide fossils, and their precise correlation is still problematical, though plant remains in the Tesnus are definitely of Carboniferous age.

In contrast to this geosynclinal section, that in the Hueco Mountains is much thinner, and is very largely of limestone. It may be regarded as a foreland section. The total thickness does not exceed 2,000 feet. The smaller areas in the Diablo and Franklin mountains are of the same facies.

At the base is the Helms group, which is from 400 to 700 feet in thickness and consists of three well-defined members. The lowermost consists of shale and thin limestone, having a bed of white chert 50-75 feet in thickness near the base. This is overlain by buff cherty flaggy limestones that thin out toward the southeast, and are followed by a sandy limestone and sandstone member, thickening southeasterly. At the last exposure in the southern Huecos, on Rancheria Mountain, it consists mostly of sandstone and shale. This upper member contains Chester fossils, but the behavior of the three members leads one to suspect that the group is not a simple unit, but may contain beds of several ages. This is confirmed by the discovery in the Franklin Mountains of Devonian fossils[1] in the lower member, in shales above the chert.

The Helms is followed by 75-150 feet of limestone, chert, and siliceous shale containing a Bend or Morrow fauna, including *Michelinia* and a number of brachiopods which are not identifiable with known forms from higher up in the Pennsylvanian. This is separated by an erosional unconformity from the overlying beds. The eroded upper surface of the Bend is well exposed at several places in the southern Hueco Mountains, as on the west face of Rancheria Mountain.

It is succeeded by 900 feet of massive limestone containing great masses of *Chaetetes*. The fusulinid, coral, and brachiopod fauna of the limestone indicate a correlation with the Strawn group, though the Strawn faunas of the type area are impoverished and lacking in distinctive character on account of their clastic environment. The fauna of this limestone also bears a close relation to many Carboniferous faunas of hitherto unknown relationship in the Cordilleran province, including that

[1]Identified by Edwin Kirk; see note by N. H. Darton, in *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), in press.

of the lower Naco formation of southeastern Arizona, the lower Hermosa formation of western Colorado, and the Wells formation of Idaho.

Above the beds of Strawn age are limestones rather similar in character but containing Canyon and Cisco fossils. *Chaetetes* is absent, and a zone of ***Fusulinella meeki*** occurs at the base. The uppermost beds contain Cisco fusulinids.[1] Near the top is a member of conglomerate and red beds, which is folded with the rest of the Carboniferous. The red beds are well exposed from 2 to 5 miles south of Hueco Canyon along the main escarpment of the Hueco Mountains, and for them the name Powwow is proposed, from Powwow Canyon, 3½ miles south of Hueco Canyon, which is followed by the new El Paso-Carlsbad highway.

The small Pennsylvanian outcrop in the Sierra Diablo is of Strawn age and has an angular unconformity of 3° with the Permian. The Carboniferous of the Franklin Mountains is like that in the Huecos, the Strawn limestones being especially well developed there. From the foregoing evidence it may be seen that the foreland sections, such as that in the Hueco Mountains, bear sufficient fossils to permit an adequate correlation with rocks in other regions. The faunas show a nearly complete representation of all rocks from Chester to Cisco in age. The geosynclinal sections of the Marathon Basin and the Solitario, however, present difficulties of correlation. Plentiful fossils in the Gaptank formation prove its correlation with the Canyon and lower Cisco. The underlying Haymond lies beneath beds of lower Canyon age, and therefore with little doubt correlates with the Strawn, which it resembles in lithology and total thickness. The age of the Dimple and Tesnus, which together are about 4,000 feet in thickness, is still uncertain. No diagnostic fossils have so far been collected from them,[2] though the scanty plant remains of the Tesnus show it to belong to the Carboniferous. A comparison of sections leads one to suspect that the Dimple may represent the Bend and the Tesnus the Chester; the occurrence of fossiliferous beds of these ages in the Hueco Mountains shows clearly that seaways extended into western Texas during Chester and Bend time. Furthermore, the fact that beds of Chester age in the Hueco Mountains thicken and become more clastic toward the southeast suggests that they are the northwestern extension of a thicker geosynclinal deposit, which may well be the Tesnus.

[1]Identifications by C. O. Dunbar.

[2]After this paper was written, in the summer of 1929, G. H. Girty and the senior writer collected a small brachipod fauna from the Dimple formation 1½ miles northwest of Haymond. It is believed that the fauna contains enough diagnostic fossils to show the correlation of the Dimple formation with some degree of certainty, but a report can not be made until the fossils are studied in detail by Dr. Girty.

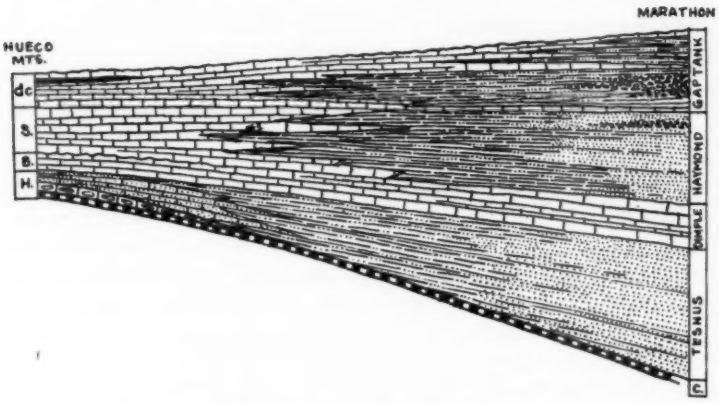

FIG. 3.—Schematic stratigraphic diagram of region between the Hueco Mountains and the Marathon Basin to show possible relations between Carboniferous rocks of the geosyncline and the foreland area.

It is not improbable that the white chert underlying Devonian fossiliferous beds in the Franklin and Hueco mountains corresponds with the Caballos novaculite of the Marathon Basin, thus adding weight to Baker and Bowman's original correlation of the Caballos with the Devonian Arkansas novaculite of Oklahoma and Arkansas.

THE CABALLOS DISTURBANCE

Carboniferous time in western Texas was closed by the Caballos disturbance, which brought about strong deformation in the geosynclinal area of the Marathon Basin and the Solitario, and produced gentle folding in the foreland area of the Diablo and Hueco mountains.

In the Marathon Basin the structure consists of asymmetrical northeast-trending folds, in part isoclinal, and in part broken by thrust faults. Strangely enough, the deformation was accomplished with comparatively little metamorphism. The most striking manifestation of the disturbance was the Dugout Creek overthrust, which is exposed in the northwest part of the Marathon Basin.[1] The overriding Caballos, Maravillas, and Marathon strata rest with nearly flat overthrust contact on beds as young as Cisco in age, as shown by their ammonoid and fusulinid fauna. The known displacement on this thrust is more than 6 miles.

[1] P. B. King, "The Dugout Creek Overthrust of West Texas," (abstract) *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), in press.

Conservative estimates in the folded belt of the Marathon Basin, which has a known width of 40 miles, show that its original width was about 60 miles. Along the northern side of the basin the strongly folded Carboniferous strata are overlain with great unconformity by the Wolfcamp beds of the lower Permian.

Field work by the writers has shown that the angular unconformity between the Permian and Pennsylvanian reported by Beede[1] in the Hueco Mountains, and that between the "Hueco limestone" and early Paleozoic strata reported by Richardson[2] in the Diablo Mountains are a part of the Caballos disturbance and were produced at the end of the Pennsylvanian. These unconformities represent the gentle folding of a foreland area.

In the northern Hueco Mountains the basal Permian rests on beds of Cisco age, but southward along the range it overlaps downward across progressively older beds. At a locality 2.5 miles south of Coyote Tanks, at the south end of the Hueco Mountains, the Permian directly overlies the Silurian Fusselman dolomite. In the Diablo and Carrizo mountains near Van Horn the basal Permian rests on the pre-Cambrian over a considerable area, though at the north and east the lower Paleozoic appears beneath the unconformity. At the northernmost exposure of the base of the Permian in the Diablo Mountains, near the mouth of Marble Canyon, beds of upper Wolfcamp age rest with angular discordance on limestones having a Strawn fauna.

PRINCIPLES OF PERMIAN CORRELATION

General conditions of Permian sedimentation.—The Permian of western North America was deposited in two seaways, extending inland from western Texas. One lay in the present Cordilleran area, the other in the Mid-Continent area. They appear to have been more or less independent of each other. The Cordilleran deposits exhibit all the characteristics of a gradual marine overlap. The seas spread most widely in Leonard (Phosphoria-Kaibab-San Andres) time, when an embayment encroaching from western Texas was joined in the northwest to the Phosphoria sea, an Arctic seaway having faunal affinities with European Russia. The joining of the embayments brought about an invasion of West Texas by boreal faunas, which mingled there with the cosmopolitan life of the Tethyan region.

[1] J. W. Beede, "Notes on the Geology and Oil Possibilities of the Northern Diablo Plateau in Texas." *Univ. of Texas Bull. 1852* (1918), p. 15.

[2] G. B. Richardson, *Van Horn Folio*, U. S. Geol. Survey (1914).

In contrast, the Mid-Continent area exhibits the features of a gradually regressive sea. At the beginning of Permian time the seas extended into the interior beyond Nebraska, but near its close they had vanished from the greater part of the interior, and remained only in western Texas. As the marine waters retreated, continental deposits were spread in their wake, transgressively replacing the marine sediments. Thus, for example, the Wichita Red-beds of northern Texas pass southward along their outcrop into the Albany marine shales and limestones, while the Clear Fork, which overlies the Albany, and which is composed mostly of red beds on the outcrop, is shown by drilling to grade into limestone beneath the surface toward the west. Salt beds likewise rise in the section toward the southwest. The Wellington salt beds of Kansas, and the salt beds of the Amarillo area, are probably of Clear Fork age; those at Amarillo lie below the Blaine formation.[1] The great salt deposits of the southern Staked Plains, on the other hand, are much younger, and lie above the Big lime[2] which includes rocks of Blaine age.

The regressive character of the Permian deposits gives rise to a number of distinctive facies which transgress southward on the time units, as suggested diagrammatically in Figure 4.

In part of trans-Pecos Texas, normal marine conditions persisted, allowing the growth of a rich marine fauna of cosmopolitan character. The deposits of this marine facies consist of limestone, sandstone, shale, and, in the Glass Mountains, of a considerable thickness of radiolarian chert. Farther inland, the normal marine facies gives place to a dolomite facies, which seems to mark a transition to the deposits of salt and red

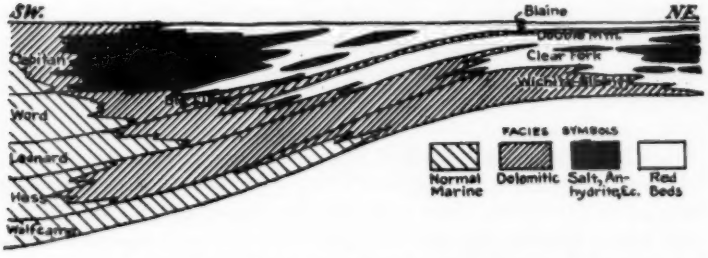

FIG. 4.—Schematic stratigraphic diagram between the Glass Mountains and northern Texas, to show arrangement of facies in the deposits of the regressive Permian sea.

[1]C. N. Gould and R. Willis, "Tentative Correlation of the Permian Formations of the Southern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927), p. 438.

[2]E. C. Edwards, "Stratigraphic Position of the Big Lime in West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 724.

beds. The dolomite is probably the result of the diagenetic alteration of limestone by highly saline marine or lagoonal waters. That the waters were less hospitable to life is indicated by the gradual dropping out of many forms characteristic of the open sea facies. There is a decrease in the number of brachiopods and an increase in the number of pelecypods and gastropods. Farthest inland, anhydrite, salt, and red beds were deposited.

The lateral change from one facies to another may be gradual, or it may be very abrupt. In trans-Pecos Texas, individual facies extend over wide areas, but there are abrupt changes from one facies to another. Thus, the section of the marine facies of the western Glass Mountains very closely resembles that of the Guadalupe Mountains, yet the rocks of the eastern Glass Mountains resemble neither, being of the dolomitic facies. The facies boundary between the Gym (dolomitic) and the Chupadera (gypsum and red bed) facies is likewise abrupt, and coincides with the Texas-New Mexico boundary (Fig. 5).

Correlation by physical criteria.—These general relations must be kept in mind while attempting the correlation of Permian rocks. Although the variations in facies and fauna within the Permian system result in many puzzling relationships and have given rise to much confusion, the writers believe that the problems of Permian correlation are not insuperable and will be established by means of faunal and physical criteria.

Physical criteria that have been utilized consist of the lateral tracing of strata, and a comparison of the position of unconformities and of the lithology in separated sections. Of these, the first is of the greatest value and must always have a definite place in work upon the Permian. Its importance has been clearly demonstrated, for example, in the Mid-Continent area, where we now know with a considerable degree of certainty the correlation of all the formations in the area between Nebraska and central Texas, as a result of the slow, painstaking tracing of outcrops by geologists during the past forty years.

There are, however, grave dangers resulting from correlation by physical evidence alone. The facies changes of the Permian previously described make it difficult, if not quite impossible, to establish a correlation upon comparisons of lithology alone. Correlations between the Permian outcrops on the east and west margins of the Staked Plains by this means are subject to errors resulting from profound facies changes, yet many such correlations have been attempted, since the time of Tarr,[1]

[1] R. S. Tarr, "Reconnaissance of the Guadalupe Mountains," *Geol. Survey of Texas Bull.* 3 (1892), pp. 31-33.

who in 1892 endeavored to correlate the Guadalupe Point section with the Pennsylvanian of central Texas. He argued that it could not be Permian, because of its non-red character, and compared the rock sequence of the Pennsylvanian along Colorado River with the sequence of strata in the Guadalupe Mountains.

In the Permian system, unconformities and their motivating diastrophism seem to be of questionable value for inter-regional correlation. The forces producing movements during Permian time are nowhere intense and resulted only in gentle folds of scarcely more than local significance. Several well-marked unconformities have been found in the Permian in different places. There is thus an unconformity between the Wolfcamp and Hess formations in the Glass Mountains, one between the Clear Fork group and San Angelo formation in central Texas, and another between the Leonard and Delaware Mountain formations in the Guadalupe Mountains. An unconformity is said also to exist in places between the Red-beds and the "Big lime" of the southern Staked Plains. All these are of different ages, and are apparently not represented outside of their own local provinces.

In spite of these objections, physical criteria for correlation have a definite place in stratigraphic work on the Permian if due consideration is also given to fossil evidence and to the principles underlying facies changes in the system. Time units established by means of fossils in the normal marine facies of the Permian in western Texas must be carried farther inland into the Red-bed and anhydrite facies by means of the tracing of outcrops and by progressive correlation between wells. Obviously, the accuracy of well-log correlation will be proportional to the proximity of the wells.

Correlations by paleontological criteria.—Since the changes in rock facies in the Permian system are the result of differences in the environments of sedimentation, the faunas are likewise intimately related to these variations. During Permian time, the continents were largely emergent, but a life as rich and varied as that in any of the earlier Paleozoic systems flourished on the continental shelves. In North America the normal marine facies was probably mostly confined to the edges of the continent, where its record is concealed from us, but an embayment of this facies extended inland into western Texas. The Permian deposits of the interior of the continent had an impoverished fauna, evidently controlled in part by a variation in the salinity of the sea, which shut out the varied and cosmopolitan forms.

In the normal marine facies of trans-Pecos Texas, the fauna is rich and plentiful. Furthermore, the marine facies is capable of detailed

zonation on the basis of fossils. Of the 180 species of brachiopods in the fauna, 43 per cent are restricted to a single formation and another 42 per cent to two formations. The brachiopods and ammonoids of this facies permit a correlation of the West Texas Permian with marine Permian sections in other parts of the world.

However, when these strata are traced into the dolomitic facies farther inland it is found that most of the characteristic and interesting fossils of the normal facies drop out. The groups of aberrant brachiopods containing *Lyttonia*, *Scacchinella*, *Richthofenia*, and *Teguliferina* are absent. Ammonoids and fusulinids are all but absent from New Mexico and the Cordilleran seaway, though many of the characteristic Permian brachiopods occur there. Although ammonoids and some of the fusulinids are present in the Mid-Continent area, nearly all the brachiopods have disappeared, or are represented by a few autochthonous forms which have descended from Pennsylvanian species that lived in the region. There is a corresponding increase here in the relative number of pelecypods and gastropods which appear to have lived in an unfavorable environment more successfully than the brachiopods.

The faunas of the dolomite and Red-bed facies are thus of monotonous aspect, and it is these faunas which have given rise to the widespread misconception that Permian life as a whole was of impoverished and unimpressive character. Nevertheless, many of these forms which show so little in themselves are also found in the normal marine facies of trans-Pecos Texas in association with worldwide zone fossils. The brachiopod faunas of the Phosphoria, Kaibab, and San Andres formations of the Cordilleran seaway show no great advance over Pennsylvanian forms from the standpoint of evolution, though they are distinct faunal entities. However, the elements of these faunas are all found in the Glass Mountains, high above the Pennsylvanian, in the Leonard and Word formations, in association with cosmopolitan forms widely distributed in Europe and Asia.[1]

To a certain extent the faunas of the dolomite facies lived in a special environment and underwent progressive evolution from lower to upper Permian, so that some of their species are of value for stratigraphic pur-

[1]The Kaibab-San Andres fauna is practically restricted to the upper Hess and the Leonard formation. The Phosphoria fauna, however, has its closest affinity to that of the Word. Most of the brachiopods that occur in the Phosphoria are present also in the Word, and many Phosphoria species are restricted to the Word fauna in Texas. This fact indicates that the Phosphoria is somewhat younger than most of the Kaibab; it is probable that the Phosphoria is, in part at least, equivalent to the "Bellerophon limestone" at the top of the Kaibab. It is definitely known that the Kaibab is almost wholly replaced on the north by the Coconino, only the uppermost part extending as far as central Utah.

poses. This evolution was parallel with, but distinct from, that of the normal facies. However, there is a strong tendency toward conservatism in the faunas of the dolomites, so that a great number are merely facies fossils, existing with little or no bodily change throughout Permian time. Such facies fossils persisted in the environment in which the dolomites were laid down, and during the Permian period followed the retreating seas southward from Kansas into Texas. It is probable that the pelecypods of the Whitehorse sandstone fauna, found by Beede[1] in the upper part of the Capitan limestone of New Mexico, are of this character, and that their occurrence in New Mexico is younger than that in Oklahoma.

Fallacies in Permian correlation.—It might be expected, in view of the regressive character of the Permian seas, that progressively younger beds would be found on proceeding from Kansas to West Texas, a situation actually indicated by the faunas. Nevertheless the usual practice has been to assume that the top of the Permian is everywhere a datum plane, be it Quartermaster, Capitan, or Kaibab. Correlation then becomes a matter of shifting the formations intervening between top and base up and down on the scale according to the individual preference of the correlator.

There has recently come to be a general misuse of the term "Guadalupian." As first proposed, it was intended to apply to a definite stratigraphic unit, now known to be middle and upper Permian in age. In recent years it has come to mean, either intentionally or inadvertently, the normal marine facies of the Permian, without regard for age. When such forms as *Richthofenia*, *Lyttonia*, and *Fusilina elongata* are found, they are therefore said to be Guadalupian, though "Guadalupian" fossils may in places be found as low as the base of the Permian. This usage has led Darton to state[2] that the unconformity in the Guadalupe Mountains was of no consequence because Guadalupian fossils occurred both above and below it, a statement which is true enough if the term Guadalupian is used to designate a facies, even though the hiatus represents nearly half of Leonard time.

Probably the most serious fallacies in Permian correlation result from the persistence of old broad units which have little or no meaning for precise stratigraphic purposes, although they have served an admirable purpose in reconnaissance geology. The Hueco limestone of Rich-

[1] J. W. Beede, "Correlation of the Guadalupian and the Kansas Sections," *Amer. Jour. Sci.*, (4), Vol. 30 (1910), pp. 135-36.

[2] N. H. Darton, "Red Beds and Associated Formations in New Mexico," *U.S. Geol. Survey Bull. 794* (1928), p. 225.

ardson has now been subdivided into a large number of different stratigraphic units of Mississippian, Pennsylvanian, and Permian age, and the name "Hueco" should now be definitely discarded, though it has been in use for many years. Likewise, the continued use of the name "Guadalupian" is inadvisable. It has been so extended as to be practically synonymous with "Permian," and preservation of the name will undoubtedly lead to continuation of the past loose terminology.

Before precise correlations can be made in the Permian, these and other broad units must be either restricted or abandoned. An example of the dangers resulting from this laxity of usage is the following.

> Beede in 1920 correlated the Wichita formation with the Chupadera formation of southern New Mexico. Darton has traced the Chupadera.... southward into the Capitan and Delaware Mountain limestones of the Guadalupe Mountains of Texas. On the basis of this work the Capitan and Delaware Mountain formations of northern trans-Pecos Texas would appear to be the equivalent to at least the upper part of the Wichita formation.[1]

The evidence on which this conclusion is based is probably largely correct, but the conclusion itself is untenable. The terms Wichita,

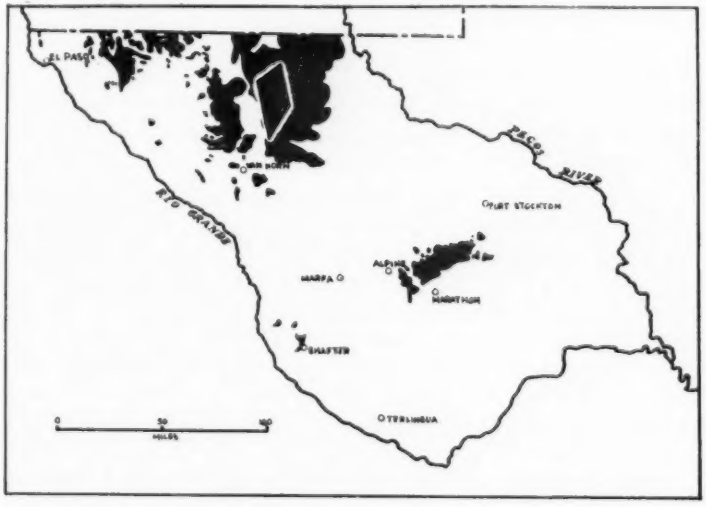

FIG. 5.—Map of trans-Pecos Texas to show area of outcrop of Permian rocks (in black).

[1]Howard W. Hoots, "Potash Investigations in Texas," *U. S. Geol. Survey Bull. 780-B* (1925), p. 80.

Chupadera, and Delaware Mountain are not used here with enough precision to permit correlations of any value.

PERMIAN ROCKS

Permian rocks outcrop in the Glass Mountains, the Delaware-Guadalupe Mountains, and in the Diablo Plateau. Smaller areas are found in the Franklin Mountains, the Finlay Mountains, and near Shafter. The Permian of this region comprises the thickest and most complete section in North America, and, as stated above, most of the beds are of the normal marine facies. The Permian section in the Glass Mountains is most satisfactory as a standard of reference because these mountains present a continuous section from the base to the top of the system. In the better known section in the Guadalupe Mountains only the upper Permian is exposed, so that the beginnings of the evolution and development of the Permian faunas is here concealed from us.

The Permian rocks in the Glass Mountains reach 6,500 feet in thickness and nearly the whole section is marine. The section has been divided into the following formations:

Bissett formation
Unconformity
Capitan formation
Word formation
Leonard formation
Hess formation
Unconformity
Wolfcamp formation
Great unconformity

Some of the details of the Glass Mountain stratigraphy have been presented elsewhere,[1] and need not be repeated here. The rocks consist very largely of limestone and dolomite, and are notable for their great lateral variations in thickness and lithology. The basal formations contain much conglomerate in the western part of the mountains. In this part of the range the Leonard and Word formations, aggregating 3,000 feet in thickness, consist of conglomeratic limestone, sandstone, clay shale, and siliceous shale crowded with the tests of *Radiolaria*. Toward the east these lower formations change very largely into limestone and dolomite. Ammonoids occur at several levels. The lowest zone, at the base of the Wolfcamp, contains the *Uddenites* fauna, shown by J. P. Smith[2]

[1] J. A. Udden, "Notes on the Geology of Glass Mountains," *Univ. of Texas Bull. 1753* (1917).
P. B. King and R. E. King, "The Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Univ. of Texas Bull. 2801* (1928), pp. 109-45.

[2] J. P. Smith, "Transitional Permian Ammonoid Faunas of Texas," *Amer. Jour. Sci.* (5), Vol. 17 (1929), pp. 63-80.

to be of very early Permian age. Above this, the genus *Perrinites* is found at several levels, and ranges as high as the top of the Leonard. The highest known ammonoid fauna, in the Word formation, contains the middle Permian genus *Waagenoceras*.

The formations of the upper 2,600 feet of the Glass Mountain strata are a great mass of dolomite. These were named the Vidrio, Gilliam, and Tessey formations by Udden, but the writers have been able to show that these units do not maintain their identity throughout the length of the range. It is therefore proposed to reduce them to the rank of members, and to call the group of dolomites the Capitan formation; paleontologic and lithologic evidence indicates that they are of the same age as the typical Capitan formation.

Permian beds of the same facies make up the Delaware and Guadalupe mountains. They have here been subdivided into the Capitan limestone above, and the Delaware Mountain formation below. The Delaware Mountain formation has been divided into the following members:

Upper dark limestone
Delaware Mountain sandstone
Basal black limestone

The Upper dark limestone contains a fauna closely related to the uppermost Word limestones exposed along Hess Canyon in the Glass Mountains, and it is concluded that the two upper members of the formation correspond to the Word. As shown by Baker[1] and Darton,[2] the Delaware Mountain sandstone rests with great unconformity on the "basal black limestone." Since the latter is well exposed in Bone Canyon, on the west side of the Guadalupe Mountains, the name Bone Canyon is proposed for it. Its fauna indicates that it is of Leonard age. A short distance north of Bone Canyon, a wedge of gray limestone appears beneath the unconformity and separates the Bone Canyon member from the Delaware Mountain sandstone.

From this discussion it may be seen that the Delaware Mountain formation, as originally defined, is not a natural group, but consists of beds of Leonard and Word age, separated by an unconformity. For this reason it is here suggested that if the term Delaware Mountain be retained, it should be restricted to the beds above the Basal black limestone.

[1]C. L. Baker, "Contributions to the Stratigraphy of Eastern New Mexico," *Amer. Jour. Sci.* (4), Vol. 49 (1920), pp. 99-126.

[2]N. H. Darton, "Red Beds and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), pp. 225-27 and Fig. 94.

The Delaware-Guadalupe Mountains are separated from exposures on the west by the long narrow bolson of Salt Flat. Beyond it rise the scarps of Sierra Diablo, which is the eastern rim of the Diablo Plateau.

In the Sierra Diablo, Permian rocks of the normal marine facies are again exposed. The Delaware Mountain sandstone crops out at the northern end of the range. It rests on a gray limestone which is evidently the equivalent of the gray limestone overlying the Bone Canyon member north of Bone Canyon in the Guadalupe Mountains. Near the base of the Delaware Mountain is a thin bed of gypsum, for which the name Dos Alamos gypsum is suggested, from its exposures near Dos Alamos, or Cottonwood Wells, due west of Guadalupe Point on the west side of Salt Flat. The gypsum member suggests a retreat and readvance of the seas, and thus confirms the existence of an unconformity at the base of the Delaware Mountain sandstone.

The gray limestone below the Delaware Mountain sandstone has a thickness of 500 to 1,000 feet, and contains *Productus ivesi* and other forms which serve to correlate it with the Leonard on the one hand, and the San Andres on the other. It is here proposed to call it the Victorio Peak member of the Leonard formation, because of the prominent exposures at the summit of the mountain of that name, which is a conspicuous promontory of the Sierra Diablo scarp.

Below it is the Bone Canyon member, 500 to 1,000 feet thick, which is underlain conformably by about 500 feet of massive limestones bearing a rich Hess fauna. At the base of the Permian in the Diablo Mountains, and resting on various older formations, are a few hundred feet of shales and thin limestones with an upper Wolfcamp fauna.

West and south of the Sierra Diablo, the normal marine facies passes abruptly into a dolomitic facies with an impoverished fauna. The limestones and dolomites of this facies are here called the Gym formation (Fig. 6). This term is extended from the Deming area of southwestern New Mexico, where the name was proposed by Darton[1] for rocks of the same age and facies. Rocks of the Gym facies are found in the Wiley, Carrizo, Van Horn, and Eagle mountains south of Van Horn. They make up the bulk of the Diablo Plateau, extending east to within a few miles of the rim of the Diablo range, where they intergrade with the normal marine facies. The Gym is also exposed in the Hueco Mountains, the Franklin Mountains, and near Deming, New Mexico. It constitutes the upper part of the Naco limestone of southern Arizona.

[1]N. H. Darton, "Geology and Underground Water of Luna County, New Mexico," *U. S. Geol. Survey Bull. 618* (1916).

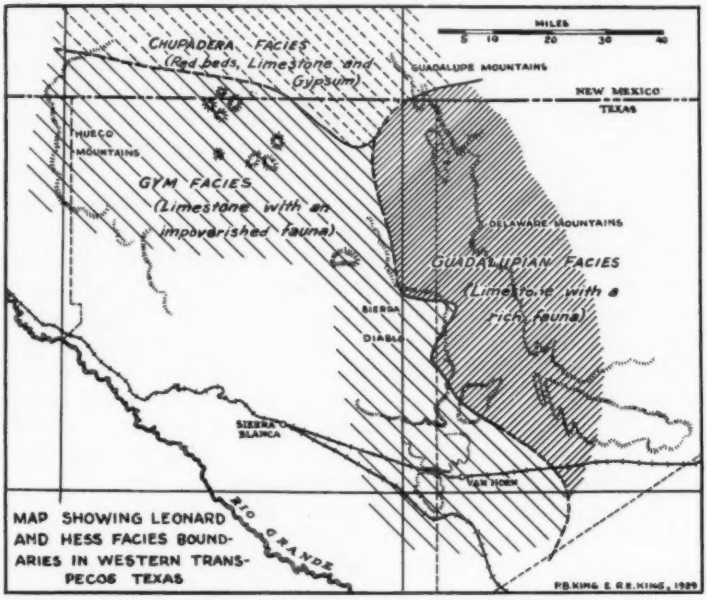

FIG. 6.—Map of northwestern part of trans-Pecos Texas, to show distribution of facies in Hess and Leonard formations.

The Gym fauna is an impoverished one, made up of gastropods, pelecypods, and a few brachiopods, including especially *Composita mexicana* and *Pugnoides texanus*. The basal beds in the Hueco and Franklin mountains also contain plentiful *Schwagerina*. This lower part of the formation may be either of upper Wolfcamp or lower Hess age, but probably the former. The fauna of the Gym formation has a remarkable resemblance to the "Upper Carboniferous" fauna of the Andes.

Near the New Mexico line, the Gym limestones of the Diablo Plateau interfinger with red beds and gypsum of the Chupadera formation, which is widely distributed over central and southeastern New Mexico. A few tongues of this facies extend south of the boundary into Texas; a red-bed member lies between limestones in the upper part of the Gym of the Hueco Mountains, and thick gypsum layers are interbedded with Gym limestones southeast of the Cornudas Mountains.

Having made this survey of the outcropping Permian rocks in trans-Pecos Texas, we may now turn to the problem of their correlation. From the standpoint of thickness alone, the Permian section of trans-Pecos Texas would seem to occupy a longer span of time than the beds exposed farther north and northeast, and paleogeographic evidence indicates that this was the last part of the continent to have been occupied by the retreating Permian seas.

This supposition is confirmed by the faunas. The brachiopods of the San Andres, at the top of the Chupadera in New Mexico, and of the Kaibab in Arizona, are nearly all found in the Leonard formation of the Glass Mountains, and in the Victorio Peak member of the Leonard in the Diablo Mountains. Although, as Darton[1] reported, the Delaware Mountain and Capitan formations pass northward in southern New Mexico into rocks of the Chupadera facies, they probably do not extend far in this direction, for the San Andres fauna, which occurs near the top of the typical Chupadera in central New Mexico, is certainly of Leonard age. The Chupadera equivalents in the southern Guadalupe Mountains are the Bone Canyon and Victorio Peak limestones.

Evidence presented by Gould and Willis[2] indicates that the San Andres is the lateral equivalent of the Blaine formation of the Mid-Continent area, whose Leonard age is proved by the occurrence of *Perrinites hilli*, a species exceedingly close to *Perrinites vidriensis*. *Waagenoceras*, which appears in the Word formation, above the Leonard in the Glass Mountains, does not occur in central Texas, but the fact that a variety of *Dielasma schucherti* Beede found in the Whitehorse sandstone of Oklahoma occurs in the middle of the Word, suggests that the part of the Double Mountain group above the Blaine is of Word age.

The change from the genus *Perrinites* to the genus *Waagenoceras* represents a stage in the evolution of the Permian ammonoid group *Cyclolobinae*, and appears to be of value not only for local, but for world-wide correlations. At Las Delicias, Coahuila, *Perrinites* is found thousands of feet below beds with *Waagenoceras* and associated Word forms. In Timor, according to J. P. Smith,[3] *Perrinites* occurs in the Bituani beds, and *Waagenoceras* in the Basleo and Weld-weleve beds, the next higher horizons in the section, but they do not occur in association.

[1]N. H. Darton, "Guadalupe Group," *Bull. Geol. Soc. Amer.*

[2]C. N. Gould and R. Willis, "Tentative Correlation of the Permian Formations of the Southern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927).

[3]J. P. Smith, "Permian Ammonoids of Timor," *Jaarb. v. h. Mijnwezen in Ned.-Indie. Verh.* (1926), p. 7.

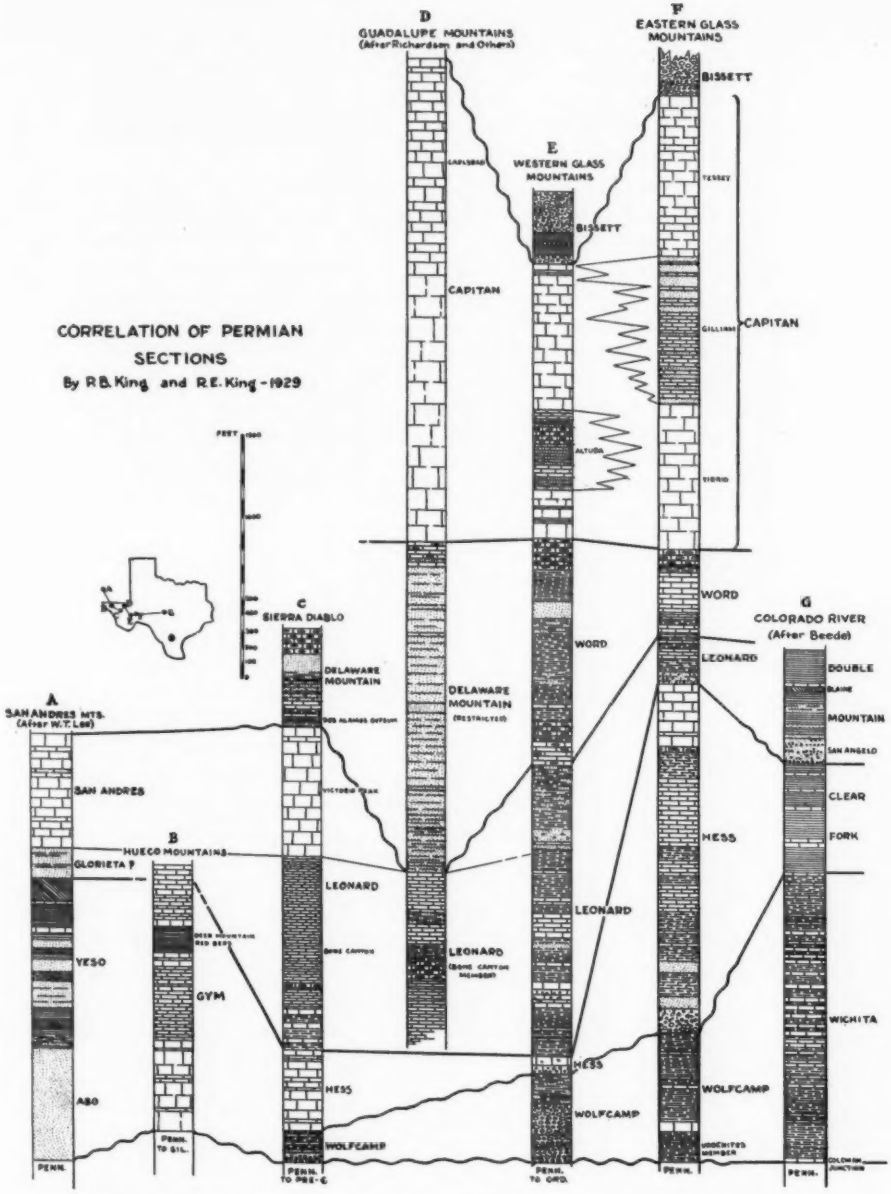

FIG. 7.—Vertical sections of Permian strata in trans-Pecos Texas, and their correlation.

The correlation of the Mid-Continent Permian below the Blaine with that of the Glass Mountains is indicated by several ammonoid zones. *Perrinites cumminsi*, an upper Wichita form, is also found in the upper part of the Wolfcamp formation, and shows that the Wolfcamp and Wichita are near identities.

In summary, the Mid-Continent Permian ranges in age from Wolfcamp to Leonard, with some of the uppermost beds possibly the equivalent of the Word. The Wichita, Clear Fork, and Double Mountain correspond roughly to the Wolfcamp, Hess, and Leonard (Figs. 6 and 7). In New Mexico, the Manzano group is probably Wolfcamp to Leonard in age, which is also true of the Permian section of the Grand Canyon of Arizona. The Kaibab of the Grand Canyon district is evidently the lateral equivalent of the San Andres of New Mexico and the Victorio Peak member of the Leonard in northern trans-Pecos Texas. The Capitan, and most of the Word, was nearly confined to trans-Pecos Texas.

PERMIAN STRATIGRAPHY OF SOUTHEASTERN NEW MEXICO AND ADJACENT PARTS OF WESTERN TEXAS[1]

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Dallas, Texas

ABSTRACT

The relationships of the Permian formations exposed in the Guadalupe, Delaware, and Apache mountains and immediately east have for some time been the subject of much dispute. These are greatly clarified by the classification of the Capitan and Apache limestones as reef formations built on the flanks of a large, subsiding basin. This basin was formed principally after the deposition of the lower Delaware limestone and then was partly filled with Delaware sand. The reefs were built during the deposition of the upper part of the Delaware sandstones. The Carlsbad limestones are considered the lagoonal facies of the reef series.

After being restricted from open marine conditions, the basin was filled with the products of an evaporating sea, the Castile gypsum and a distinct salt series.

No attempt is made to subdivide Darton's Chupadera in other parts of New Mexico.

INTRODUCTION

The stratigraphic relations of the Permian formations exposed in the Guadalupe, Delaware, and Apache mountains have been the subject of much study and discussion. Because of a lack of sufficient detailed study of sharp stratigraphic and lithological changes, these relations have not been clearly understood.

Field work by the writer, assisted by J. W. Hoover during 1928, has brought to light several interesting observations which the writer believes should aid in clarifying the interpretations of these relations.

The writer wishes to acknowledge the helpful coöperation and suggestions of G. C. Gester and H. J. Hawley.

GEOGRAPHY

The Guadalupe Mountains of southern New Mexico (Fig. 1) have an abrupt southern termination at Guadalupe Point, northwestern Culberson County, Texas. One mile toward the north is El Capitan Peak, the highest point in the state of Texas, with an elevation of approximately 8,770 feet. From Guadalupe Point, the Guadalupe Mountains ex-

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, March 8, 1929.

[2]Geologist, The California Company.

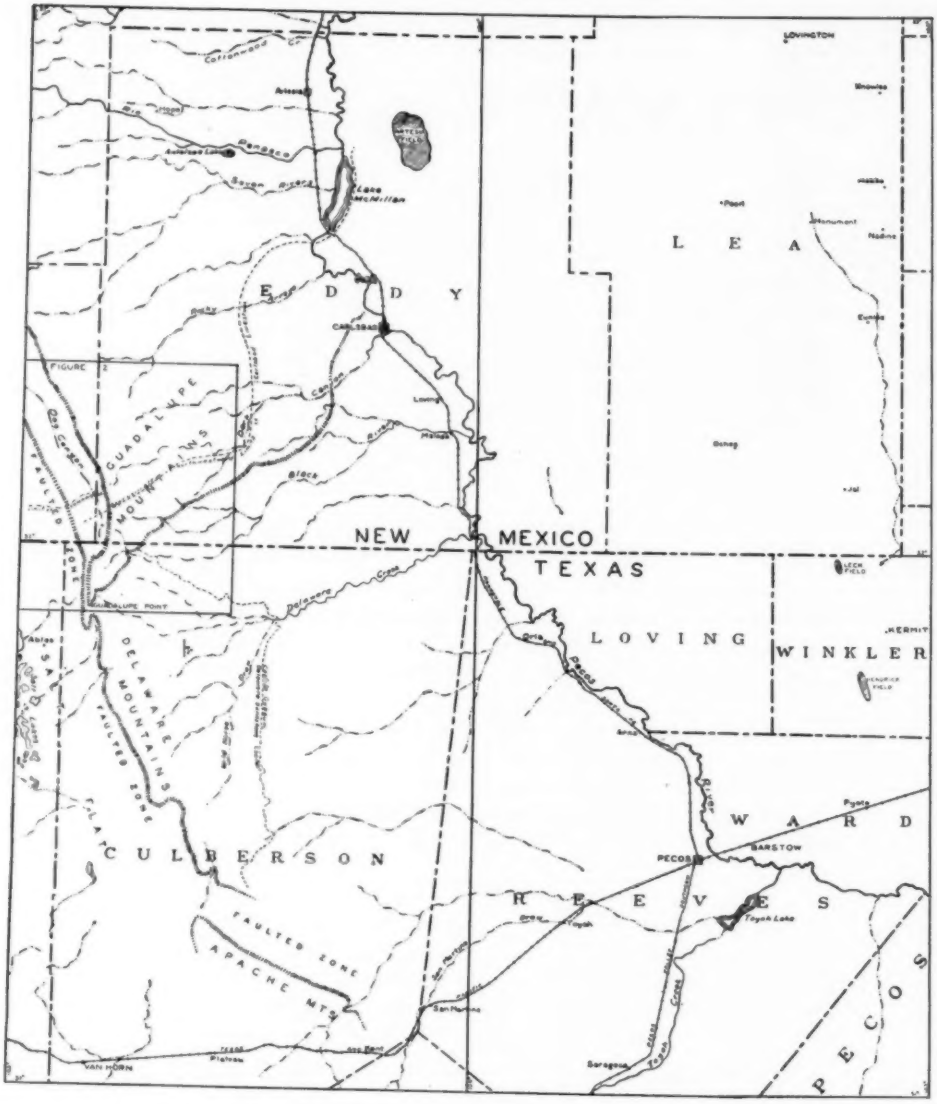


Fig. 1.—General map of southeastern New Mexico and part of western Texas.

tend north and west, merging with the broader Sacramento Mountains in north-central Otero County, New Mexico. An unnamed, subsidiary spur trends northeast from Guadalupe Point, with decreasing elevation, ending in the Pecos River valley, near Carlsbad, New Mexico. This spur has a very steep southeastern slope, the geological significance of which will be discussed later.

South of Guadalupe Point, the Delaware Mountains, with their crest about 2,000 feet lower, trend toward the south. They are terminated by the Seven Heart Gap fault zone in central-western Culberson County. The western flanks of both the southern Guadalupe and the Delaware mountains are very steep. They drop off into Salt Flat, a large, centrally-drained, down-faulted basin.

South of the Delawares, the Apache Mountains rise, trending southeast. They plunge beneath a blanket of gently-dipping Cretaceous sediments near Kent, Texas. These mountains exhibit a steep northeast scarp, facing the Seven Heart Gap fault zone.

STRATIGRAPHY

In this paper the writer deals only with the Permian formations exposed in the Apache, Delaware, and southern Guadalupe mountains, no attempt being made to subdivide the Chupadera of the regions farther north. In the Guadalupe and Apache mountains, the Permian section

TABLE I

PERMIAN FORMATIONS EXPOSED IN THE GUADALUPE, DELAWARE, AND APACHE MOUNTAINS

Guadalupe Mountains	*Delaware Mountains*	*Apache Mountains*
	Rustler limestone	
	Castile gypsum	
Capitan and Carlsbad limestones	Delaware sandstone	Apache limestone
Seven Rivers gypsum		
Queen sand		
Undifferentiated Chupadera limestones		
Delaware sandstone		
Lower Delaware limestone	Lower Delaware limestone	

consists principally of limestone, but in the Delaware Mountains the larger part of the exposed section is sandstone with an overlying gypsum series.

LOWER DELAWARE LIMESTONE

The lower Delaware limestone, Delaware sandstone, and Capitan limestone are members of the Guadalupe group, described by Tarr,[1] Richardson,[2] Girty,[3] and Darton and Reeside,[4] at their type locality at Guadalupe point. The lower Delaware limestone is a series of limestones ranging from black to gray, best exposed along the western front of the Delaware and southern Guadalupe mountains, especially near Bone Springs, from which locality the series has been given the local name of Bone Springs limestone.

The fossil content of this and the overlying Delaware sands and Capitan limestone has been well described by Girty.[5] These limestones lying beneath the Delaware sands Girty calls the Lower dark limestone of the Delaware. Although subsequently they have been found to be separated from the overlying Delaware sandstone by a pronounced erosional unconformity, the name of lower Delaware limestone is retained in this discussion because of their Guadalupian fauna. In the limestone series itself there are several striking examples of local angular unconformities, especially near Bone Springs. Local thickening and thinning of individual beds are very common.

The limestones are black, brown, and dark gray, ordinarily thin-bedded, many exhibiting a wavy, nodular appearance. The darker series commonly contains plentiful chert lenses and is bituminous. Just north of Bone Springs, the gray limes overlie the dark limes, but have been removed by erosion on the south. Three miles north of Bone Springs at least 1,000 feet of this series is exposed. North of that point, the lower Delaware limestone grows distinctly lighter-colored and seems to grade into the Chupadera formation, in southern New Mexico. The conglomerate which overlies the lower Delaware limestone contains material derived from the upper gray member, interbedded with sands of Delaware

[1]R. S. Tarr, "Reconnaissance of the Guadalupe Mountains," *Texas Geol. Survey Bull. 3* (1892) pp. 9-39.

[2]G. B. Richardson, "Report of a Reconnaissance in Trans-Pecos Texas, North of the T. & P. R. R.," *Univ. of Texas Bull. 23 (Min. Survey Bull. 9)* (1904).

[3]G. H. Girty, "The Guadalupian Fauna," *U. S. Geol. Survey Prof. Paper 58* (1908).

[4]N. H. Darton and J. B. Reeside, Jr., "Guadalupe Group," *Bull. Geol. Soc. Amer.*, Vol. 37 (1926), pp. 413-28.

[5]G. H. Girty, *op. cit.*

appearance. At Bone Springs, this conglomerate has a thickness of 100 feet, but is imperceptible north of the state line.

DELAWARE SANDSTONE

The Delaware sandstone, unconformably overlying the lower Delaware limestone, has a maximum thickness of about 3,500 feet. It is exposed in a broad area extending from the west flank across the Delaware Mountains and well down on the east flank, where it passes with seeming conformity beneath the Castile gypsum. It is also exposed on the western front of the southern Guadalupe Mountains (Fig. 2). In the latter locality, its thickness abruptly decreases from 2,500 feet to about 300 feet in the interval from Guadalupe Point to Goat Seep. This is due to overlap on the underlying limestones, to thinning of the separate members, and to gradations of some of the upper beds into overlying limestones. Directly north of Goat Seep, the Delaware sandstone seems even thinner in places. One cliff of lower Delaware limestone was found which had at least 50 feet of sandstone abutting against it, forming a very steep local erosional unconformity.

The Delaware sandstone series is composed chiefly of very fine, even-grained, gray, buff, and brown quartz sand, with some dark carbonaceous material in thin streaks and in beds with a maximum thickness of 5 feet. This carbonaceous material is ordinarily black sandy shale, but in some places is black limestone. This material is absent north of Goat Seep. In the section at Guadalupe Point, there are several beds of medium-grained, brown to buff, clean quartz sand. Some of these strata show at the base that they were laid down on uneven, eroded surfaces. In this same locality, there are many other evidences of cut-and-fill, erosion, and abrupt northwest thinning of beds.

Some thin layers of a peculiar hard green argillite are found from 400 to 500 feet below the top of the formation. Limestones are relatively rare in the series at Guadalupe Point, but increase in amount in the Delaware Mountains on the south.

Where the top of the series is found in contact with the overlying Castile gypsum on the east, it is characterized by several limestone ledges having a total thickness of about 30 feet. These are predominantly black, thin-bedded, gypsiferous, bituminous, and in places cherty. They seem to grade upward into a poorly-bedded, gypsiferous limestone sand which is included by the writer in the Castile series. On tracing the top Delaware limestone horizon northward it is found to retain its characteristics as far as a point in the SW. ¼, Sec. 15, Blk. 64, T. 1, Culberson County, where the Carlsbad-Van Horn highway crosses the

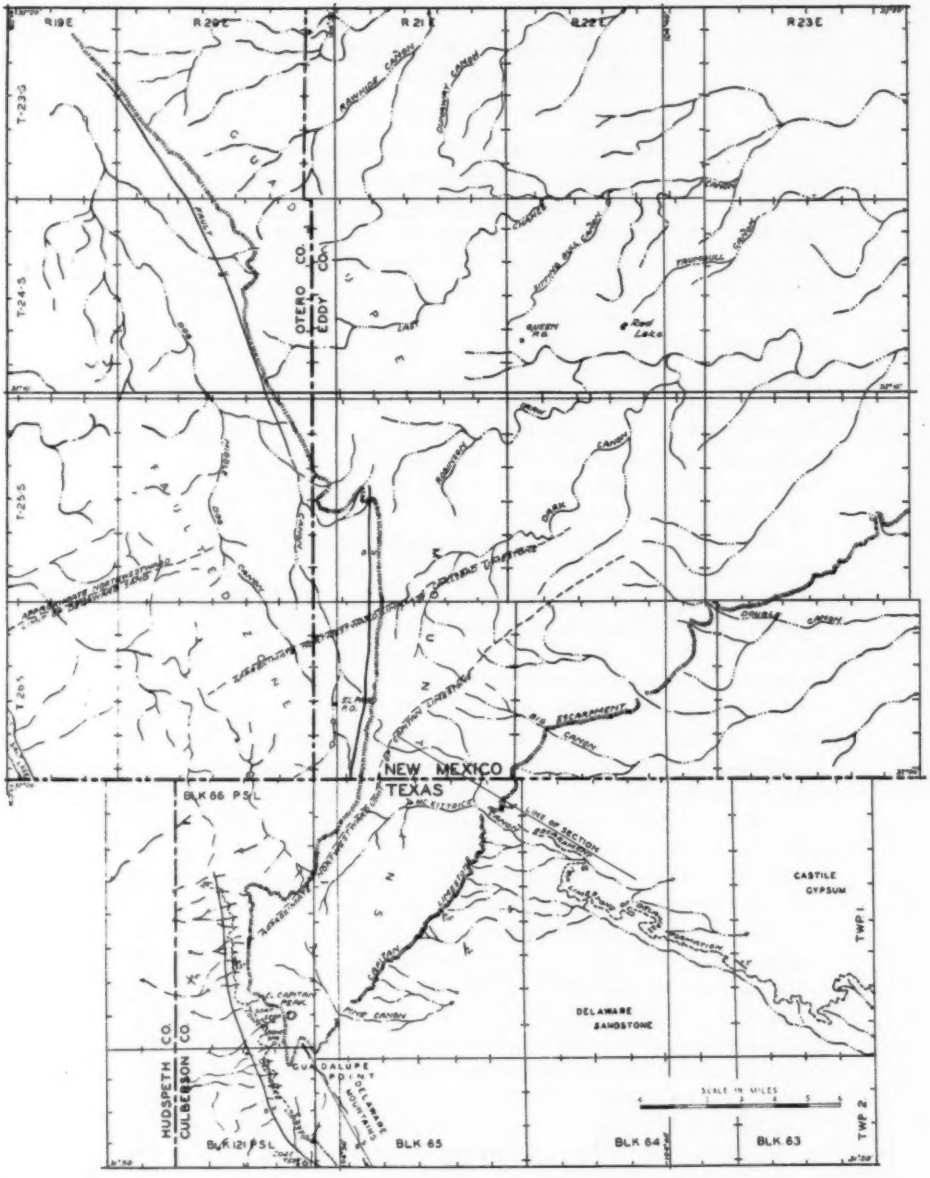


FIG. 2.—Map of southern Guadalupe Mountains showing Capitan reef escarpment and approximate northwestward limits of Delaware sandstone, Capitan and Carlsbad limestone series.

outcrop. At this locality, the section for 100 feet below the top has changed from sandstone to gray, well bedded limestone. The top member here exposed contains several ripple marks and examples of what seem to be sun cracks. Between this point and the foot of the escarpment at the mouth of McKittrick Canyon, 4 miles northwest, the top member becomes lighter in color, more massive, and much more fossiliferous. The dip steepens perceptibly, swinging a little toward the south. At the foot of the escarpment, the beds rise precipitously (Fig. 3). Some of the limestone becomes conglomeratic, and at least 300 feet of the upper Delaware series, of which the lower 100 feet has remained as sandstone, grade abruptly into massive Capitan limestone. At many places along the mountain front the same abrupt interdigitation is found. Close examination of the relationship shows that an explanation of the change by faulting or overlapping is out of the question.

CHUPADERA LIMESTONE

On the western front of the Guadalupe Mountains, north of Goat Seep, some comparatively well bedded limestones occur between the Delaware sands below and the more massive Capitan limestone above. These thicken within a short distance northward, the Capitan thinning in the same interval. Two miles toward the north the Capitan is absent, leaving the Carlsbad series, formerly above the Capitan, lying directly above this series, with the Delaware sands below. Although the writer made no fossil collections from this series, Darton[1] states that they contain Manzano fauna in southern New Mexico, and for this reason, the term Chupadera is used tentatively to designate them.

This member of the Chupadera consists principally of gray and buff limestones, fairly well bedded, which, in places, become sandy. Some of the Chupadera strata exhibit a very fine granular appearance on weathered surfaces, suggesting that they have been formed by the cementation of clastic particles of limestone. Some beds contain large quantities of *Fusilina elongata*, but the series is otherwise generally unfossiliferous.

Because of poor exposures and the concealment of the exact contact, it is not known whether this series is conformable with the Capitan. It is, however, evident that it is somewhat older than the true, massive Capitan. The contact between the Chupadera limestones and the Carlsbad was taken just above a prominent massive, hard, white, dense limestone which fractures smoothly, but has a very rough weathered

[1]Personal communication to the writer, January, 1929.

FIG. 3.—Cross section of southeastern front of Guadalupe Mountains at McKittrick Canyon. Depths shown in feet.

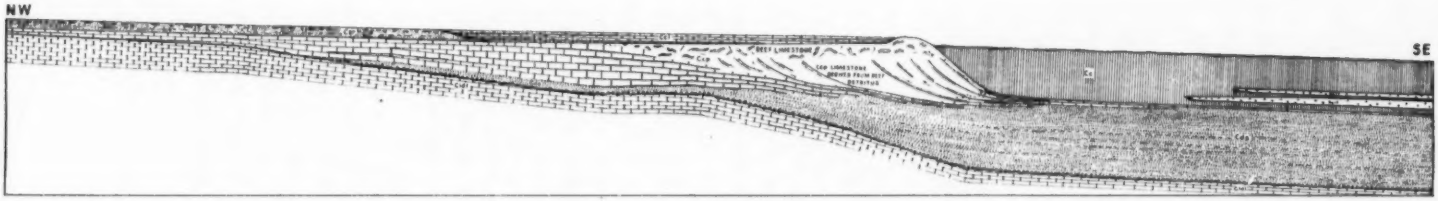


FIG. 4.—General section showing relation of Permian formations in the southern Guadalupe Mountains. *Cc*, Castile gypsum with intercalated salt; *Ccl*, Carlsbad limestone; *Ccp*, Capitan limestone; *Csr*, Seven Rivers gypsum; *Cds*, Delaware sandstone; *Cldl*, lower Delaware limestone.

surface. In places the top of this bed seems to have suffered some erosion and contains small iron concretions.

At Goat Seep, these Chupadera beds are about 1,000 feet thick, but they evidently thin toward the north, and only about 300 feet are present in Sec. 33, T. 26 S., R. 20 E. There they overlie the Delaware sand which has thinned to about 50 feet of pink and brick-colored sandy limestones. This wedging-out of the Delaware sands toward the north is accompanied in places by a remarkable convergence between the overlying and underlying limestones. Both the upper and lower contacts of the Delaware sandstone have the appearance of being slightly conglomeratic in this area.

Farther north, in Sec. 35, T. 24 S., R. 20 E., where the Delaware has completely disappeared, it is very difficult to place a contact between the upper (Chupadera) limes and the lower Delaware series. It is, therefore, not certain just how much of the former is left. The lower part of the entire section exposed contains much chert, and the upper part is characterized by plentiful *Fusilina*. This same general series, still farther north, begins to contain beds of red shale and gypsum, changing gradually into a principally non-marine facies of the Chupadera in northern New Mexico, including both the Yeso and San Andreas of Lee.[1]

CAPITAN LIMESTONE

The Capitan limestone with beds, which were deposited contemporaneously with it, is probably the youngest of the Permian marine deposits found exposed in the United States. It conformably overlies Delaware sandstone, and is exposed in a narrow band along the southeastern front of the Guadalupe Mountains as far northeast as the Carlsbad Caverns and along their western front to a point about 4 miles north of Guadalupe Point. It is the most interesting formation of the entire Permian series in this region. The maximum thickness of the Capitan limestone is about 1,800 feet, but it thins within a short distance northwest and southeast. Its outcrop is nowhere found to have a width of more than 5 miles in the Guadalupe Mountains. It persists as a band, however, to an area 25 miles northeast of Guadalupe Point, where it is covered by the overlying Carlsbad limestone and the Castile gypsum. Its subsurface continuation, as indicated by well records in southeastern New Mexico and western Texas, is much greater.

[1] W. T. Lee and G. H. Girty, "The Manzano Group of the Rio Grande Valley, New Mexico," *U. S. Geol. Survey Bull. 389* (1907), pp. 12-17.

The Capitan is made up of a series of exceedingly massive gray limestones, which are ordinarily dolomitic. It is sporadically fossiliferous, many of the forms appearing to have been partly destroyed, probably by dolomitization. Fossils are rarely seen where the rock has a gray coating on the weathered surface, but are much more common where the rock has a clean, cream-colored face. It is ordinarily coarse-grained and contains inclusions of calcite crystals and vugs with a maximum diameter of 1 foot, lined with the same material. Sand inclusions are also found, but are of irregular shape, both vertically and horizontally, appearing very much like fillings of pre-existing cavities. These and the appearance of the vugs suggest that the rock was deposited as a *rigid* mass.

At some places a peculiar type of bedding is noticed in the Capitan, resembling a gigantic form of cross-bedding. These lines of stratification are best exposed on the smooth cliffs of the west front of the Guadalupe Mountains. Bedding planes start at the top of the formation with dips toward the southeast as high as 40°, decreasing within a short distance down dip in a gentle arc to relatively slight dips at the base of the formation. Along the southeastern face of the mountains these dips are not so apparent, but constitute the only distinguishable bedding in the otherwise massive limestone. The average dip near the base of the escarpment along this line is 26° in a direction a little south of east.

The abrupt southeastern termination of the Capitan along the southeastern escarpment of the Guadalupes has long been of great interest, and it has nowhere been found to exist in this area southeast of this line. A study of the gradation between the uppermost members of the Delaware sandstone and the Capitan limestone at the mouth of McKittrick Canyon shows that, as the eastward dips of the Delaware increase abruptly at this point, they appear to approach the steep inclination of the Capitan bedding planes. It is clear that, should these lines in the Capitan be considered as true planes of deposition, the topmost beds of the Delaware would merge with the southeasternmost beds of the Capitan and rise steeply to the top of the escarpment.

It is the opinion of the writer that the Capitan limestone is a well developed fossil reef of large size that was formed during the deposition of the uppermost Delaware sands, where they are exposed at their contact with the overlying Castile gypsum. The restriction of the area from the open sea, and the cessation of marine sedimentation with the beginning of the deposition of evaporites on the southeast, evidently ter-

minated the reef growth. At least 400 feet of Delaware sand is missing at the type locality at Guadalupe Point, seemingly having graded into the Capitan there exposed.

The steeply-inclined bedding planes are evidently the detrital slopes of the offshore side of the reef, where material broken off from it has rolled down and become cemented, probably by calcareous algae known as nullipores.[1] At the foot of the reef the organic material merged with the Delaware sands which were being supplied from some other source. Northeast of the mouth of McKittrick Canyon several conglomeratic horizons are found at the foot of the reef, composed of gray and black angular fragments of limestone in a limestone matrix containing many Permian fossils. This rock shows some faint evidence of containing coral fragments.

The reef in this area evidently grew for several miles along a northeast-southwest shore line. Its steep offshore slope faced a rather large, late Permian epi-continental sea on the southeast. Sedimentation was continuing at different levels at the same time; in the lagoon behind the reef barrier, on the superficial part of the reef itself near sea-level, on its seaward flanks, and on the floor of the sea on the southeast.

Some objection to the classification of the Capitan as a fossil reef deposit may be offered because of the apparent scarcity of fossils in many places, particularly corals, and its dense, almost inorganic appearance. It is now realized, however, that corals may be a far less important factor in reef formation than has been thought heretofore, the coral growth being merely on the shallow, superficial parts of the reef mass. Nullipore algae constitute the binding agent for material on the outer slopes of the reef and even help bind the corals themselves together.[2] *Foraminifera*, *Bryozoa*, and *Echinodermata* also are very important in reef formation.[3] It is also known that loss of organic structure through dolomitization is common in present-day reefs.[4] The exceptional thickness of the Capitan is no disproof of its being of such an origin, the Great Barrier Reef of northeastern Australia, among other epicontinental reefs, having a declivity of more than 1,800 feet on its seaward face.

[1] W. M. Davis, "The Coral Reef Problem," *Amer. Geog. Soc. Spec. Pub. 9, (1928)* p. 12.

[2] A. W. Grabau, *Principles of Stratigraphy*. Second edition (1924), p. 413.

[3] A. W. Grabau, *op. cit.*, p. 393.

[4] W. M. Davis, *op. cit.*, p. 10.
A. W. Grabau, *op. cit.*, p. 445.

CARLSBAD LIMESTONE

The Carlsbad limestone, which is integrally a part of the Capitan series, is exposed in the higher parts of the Guadalupe Mountains in a band overlying the Capitan and reaching a few miles farther northwest, where, due to the pinching-out of the reef deposit, it overlies the older Chupadera limestones. Its name was suggested by Darton[1] and it was more fully described by Meinzer and others.[2] It is a series of gray, buff, brown, and pinkish-colored limestones intercalated with several buff, brown, and reddish sands. The limestones are characteristically thinly bedded, in places individual beds being less than ½ inch thick. Some of them present a distinctly granular appearance on weathered surfaces, resembling cemented lime sands. Fossils, except for *Fusilina elongata*, are rare, but fossil fragments are common.

The sand members are most extensively developed in the northwesternmost exposures, especially in Sec. 35, T. 26 S., R. 20 E. They are composed of medium-sized, sub-rounded grains of quartz, with both ferruginous and calcareous cement. In this area the entire Carlsbad series has a pinkish cast. Many of the limes are pink, red, and brown and the sands dark brown and brick-red in color. The thickness here is approximately 700 feet.

Toward the southeast the Carlsbad series thins gradually, evidently due to overlapping of the older beds on the Capitan reef mass (Fig. 5). The sands become more calcareous and fewer in this direction. The pinkish cast of the formation changes to gray and many of the limestones become more massive, taking on Capitan characteristics. Oölitic and pisolitic zones appear and constitute as much as 20 per cent of the entire thickness. These pisolites occur in masses bordered by thinly banded calcite coatings but are found in distinct beds. Their cross sections show concentric structure and their maximum diameter is 1 inch. Such pisolites are found sparingly in the Capitan also, but never to such a marked degree. It is quite possible that they are products of algal growth.

It is the writer's opinion that this series represents the lagoonal deposits laid down toward shore from the Capitan barrier reef. Their position, areal distribution, bedding, internal structure, and fossil content all suggest this origin.

That the lagoonal deposits of a barrier reef are of fine material, partly coral sands (material broken off from the reef and ground up and

[1] N. H. Darton and J. B. Reeside, Jr., *op. cit.*, p. 419.

[2] O. E. Meinzer, B. C. Renick, and Kirk Bryan, "Geology of the Carlsbad Irrigation Project," *U. S. Geol. Survey Water Supply Paper 580-A* (1928), pp. 12-13.

FIG. 5.—Carlsbad lagoonal limestone overlapping massive Capitan reef limestone. Looking southeast down McKittrick Canyon from Sec. 28, T. 26 S., R. 21 E.

washed in by wave action) and partly the results of algal and other growths in the lagoon itself has been noted.[1] The thin bedding of the series is to be expected because of the protection from wave action provided the lagoonal area by the barrier reef existing on its seaward side.

APACHE LIMESTONE

In the Apache Mountains in southeastern Culberson County, there is exposed a limestone series about 1,000 feet thick which resembles the Capitan to a marked degree. The local name of Apache limestone has been applied to it. It is composed of massive gray and white limestones, exhibiting practically the same lithological characteristics and fauna as the Capitan, and an overlying, well-bedded, pisolitic series, resembling the Carlsbad. While no fossil collections were made from it by the writer, a few forms are reported by Girty[2] and their Guadalupian age noted. It is almost certain from this and from the peculiar features of the formation that it is the equivalent of the Capitan and Carlsbad in this vicinity and it is so considered here.

The Apache Mountains trend S. 70° E. and present a steep northeast scarp, facing the Seven Heart Gap fault zone. Deep wells a few miles northeast do not encounter the Apache series, although starting in young-

[1]W. M. Davis, *op. cit.*, p. 16.
J. D. Dana, *Corals and Coral Islands*, 3rd edition (1890), p. 156.

[2]G. H. Girty, *op. cit.*

er formations, but do encounter the Delaware sands at comparatively great depths.

The upper lagoonal deposits thin out by overlapping on the underlying reef formation toward the northeast. Drainage in the mountains themselves is interrupted by long, parallel ridges, the streams flowing through gaps in them, forming series of elaborate meanders. These ridges have a distinct parallelism with the northeastern mountain front and are thought to have been originally induced by individual reefs, which, due to their hardness, tended to influence the normal course of the drainage. This same feature was observed to a lesser degree in the area where the Capitan is exposed in the Guadalupe Mountains.

It seems, therefore, that the Apache limestone is a barrier reef formation with its accompanying lagoonal deposits which grew in a band striking about N. 70° W., facing the open sea on the northeast. The conditions, except for orientation, are almost identical with those along the southeastern front of the Guadalupe Mountains.

SEVEN RIVERS GYPSUM AND QUEEN SAND

In Rocky Arroyo, T. 21 S., R. 24 E., the Carlsbad series, about 300 feet thick, is found overlying about 100 feet of brown and buff sandstone and separated from it by a thin bed of gypsiferous red shale and limestone conglomerate. From this point the Carlsbad limestone thins in a very short distance toward the northwest, being only approximately 50 feet thick at a point a half mile distant. It is evidently replaced by a gypsum and red shale series which overlies the sand. The relation is evidently that of an overlap of the Carlsbad limestone on the sand and gypsum. The slope which was overlapped formed the shore line for the Carlsbad lagoon during much of its existence. The gypsum series is everywhere separated from the Carlsbad by a conglomerate or by a zone of reworked red shale and gypsum.

This unconformity has been recognized by Meinzer and others.[1] The gypsum formation was named the Seven Rivers by them. The underlying sand series is called the Queen sand from its extensive outcrops in the vicinity of Queen Post Office, Sec. 30, T. 24 S., R. 22 E., in the Guadalupe Mountains.

The Seven Rivers series is composed chiefly of gypsum with some intercalated red shale, especially near the base, and a few gray, dense, thinly bedded limestones which are evidently inorganic in origin. The gypsum is white, gray, and greenish, of earthy aspect, poorly bedded and possibly of terrestrial origin.

[1] O. E. Meinzer, B. C. Renick, Kirk Bryan, *op. cit.*, pp. 13-15.

Along the southeastern shores of Lake McMillan, T. 19 S., R. 26 E., the remaining 30 feet of Carlsbad limestone which overlies the Seven Rivers gypsum grows more dense and inorganic in appearance toward the north. Sandy members appear and this part of the series gradually interfingers with the gypsum and red beds. It seems evident that the shore line of the lagoon at this time was gently sloping and the limes were more subject to the admixture of gypsum and detrital material than was the case at the time of the deposition of those limestones overlapping the relatively steeper shore in Rocky Arroyo.

CASTILE GYPSUM

Southeast of the Capitan escarpment, on the southeastern front of the Guadalupe Mountains, everywhere above the Delaware series is exposed a thick series of gypsum and anhydrite called the Castile gypsum. This series has been shown by well records south of Carlsbad, New Mexico, to be more than 2,500 feet in thickness.

It overlies the Delaware sandstone with seeming conformity, and is composed of granular gypsiferous limestone at the base with an immense thickness of purer anhydrite above. This anhydrite is ordinarily banded with very fine laminations of bituminous and calcareous material. Some sand and shale beds are found in wells, but, on the whole, it is remarkable for its purity and the comparative absence of detrital material. Farther east from the Castile-Delaware sand contact, deep wells in western Reeves County encounter salt horizons in the series.

It has long been supposed that the Castile gypsum and Capitan limestone were of approximately the same age, due to their juxtaposition on the southeastern escarpment of the Guadalupe Mountains and because both are found to overlie Delaware sand seemingly conformably. The contact between the Capitan and Castile on this escarpment is ordinarily masked by a blanket of terrace gravels. At the mouth of Rattlesnake Canyon, T. 25 S., R. 24 E., however, an outcrop of pure gypsum is found within a few hundred feet of Capitan limestone (Fig. 6). The superposition of the gypsum upon the limestone at this place has been noted by Darton.[1]

The formation of this escarpment has been suggested by several to be due to the undermining and removal of a wedge of Capitan which originally extended southeast over the Castile. The gradual overlapping of the entire thickness of Capitan and Carlsbad on its northeastward plunge from Guadalupe Point to Carlsbad makes this almost a physical impossibility.

[1] N. H. Darton and J. B. Reeside, Jr., *op. cit.*, p. 420.

FIG. 6.—Juxtaposition of Castile gypsum (on creek bank) and Capitan limestone (hills on right). Looking southwest from mouth of Rattlesnake Canyon, T. 25 S., R. 24 E.

The Castile gypsum is the product of an evaporating basin, recurrently charged, of which the northwestern rim was the Capitan fossil reef escarpment.

RUSTLER LIMESTONE

In the Rustler Hills, central-eastern Culberson County, the Rustler limestone is exposed. It is a dense, dolomitic, brecciated limestone, rough and pitted on weathered surfaces, with a maximum thickness of 375 feet. It shows a wide divergence of dip toward the east, from that of the Delaware sandstone. In the southern Delaware Mountains, on the northeast side of Seven Heart Gap, there is only approximately 200 feet of gypsiferous limestone of the lower Castile between it and the top of the Delaware, but on the east, wells in western Reeves County show an interval of more than 2,000 feet between the two formations. This indicates that it was deposited after the basin on the east was well filled with evaporites. Just how far the Rustler limestone extends in the subsurface is not known, some wells in southeastern Culberson County evidently missing it within a few miles of its outcrop.

CORRELATION

The logical correlation of the Permian of southeastern New Mexico and western Texas in the face of the foregoing evidence (Fig 4) differs greatly from those previously made. The conception of the Capitan

limestone as a fossil reef formed during the deposition of the upper few hundred feet of Delaware sands as exposed in their contact with the Castile gives us a new conception of the paleogeography of the time, making it certain that the Castile gypsum is the younger of the two formations. The presence of conglomerates, ripple marks, and sun cracks in the uppermost beds of the Delaware near the reef, implying very shallow waters at that time, together with the fact that the Delaware sands and Capitan can be shown to intergrade, make it extremely improbable that the Capitan marine limestone also intergrades with the non-marine Castile along the sharp line of the escarpment. At the point of closest contact between the two formations, each retains its own characteristics. The only calcareous part of the lower Castile series is at its base, where the gypsiferous limestones are distinctly granular and may have been derived from erosion of the topographically higher Capitan as well as from inorganic precipitation.

Heretofore the majority of the geologists working in this area have pointed out the peculiar juxtaposition of marine limestone and evaporite series on the Capitan escarpment and in Rocky Arroyo as examples of very abrupt interdigitation of the two facies and have been thus tempted to make subsurface correlations with this in mind as occurring on the surface. Both examples of this supposed sudden change of great thicknesses of marine strata to non-marine within very narrow limits are evidently caused by overlapping against comparatively steep surfaces, in one case of evaporites upon marine limestones, and, in the other, of marine limestones forming on the floor of a quiet lagoon upon the non-marine shore line of that lagoon.

Although the Capitan limestone and Delaware sandstone have been described as separate formations at their type locality at Guadalupe Point, there seems no valid reason why the upper few hundred feet of Delaware sandstone, which has there graded into Capitan and is, therefore, missing from the Delaware series, can not be included in the Delaware, the Capitan being their time equivalent, but a peculiar local formation of upper Delaware age.

The classification of the Capitan as a fossil reef is the most tenable in the light of its peculiar lithology, bedding, variations, areal distribution, and even of its fauna. The induced consequences of such a classification have met very well the observed features of both this and associated formations in the field.

The crustal movements influencing the formation of this reef are of exceptional interest. The thinning and overlapping of the Carlsbad

series upon the Capitan toward the southeast in the Guadalupe Mountains indicates that the immediate area was undergoing subsidence at that time, the level of reef growth rising as it built outward toward the southeast. The rate of subsidence was small as compared with the rate of outward growth as indicated by the slow thinning of the beds. That this same movement was active before this time is shown by the thickening of the Delaware sands and the inclination of the lower Delaware limestone toward the southeast. This observed feature is a field confirmation of the original theories of Darwin and Dana, recently reaffirmed by Davis,[1] that reefs grew principally on subsiding foundations.

The great thickness of the Capitan and its remarkable lateral persistence of at least 25 miles in the Guadalupe Mountains, 20 miles in the Apache Mountains, and possibly 25 miles in the Glass Mountains on the southeast, where P. B. King and R. E. King[2] have suggested both the time equivalency with the Capitan and the reef origin of the Vidrio, Gilliam, and Tessey formations, make it and its related formations the largest fossil reef yet described with the exception of the Schlern dolomite of Triassic age in the southern Tyrol.[3] The similarity evidently existing between this latter formation and the Capitan is noteworthy.

A more detailed study of the Capitan might be of great value in clarifying our conception of the mode of formation of modern reefs, both epi-continental and oceanic.

[1]W. M. Davis, *op. cit.*

[2]P. B. King and R. E. King, "The Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Univ. of Texas Bull. 2801* (1928), pp. 139-40.

[3]A. W. Grabau, *op. cit.*, pp. 434-37.

CORRELATION OF PERMIAN OUTCROPS ON EASTERN SIDE OF THE WEST TEXAS BASIN[1]

A. M. LLOYD and W. C. THOMPSON[2]
Wichita Falls, Texas

ABSTRACT

This paper consists of a correlation and brief description of Permian outcrops of West Texas in an area extending from Cretaceous rocks in Taylor and Nolan counties northward to Red River. Outcrops in the different counties were traced in the field by the writers and secured from various company and independent geologists, and a map was compiled showing the correlation and trace of the principal beds in detail. Columnar sections across the outcrops are used to illustrate the vertical relation of beds in different parts of the area. Names have been suggested for certain members previously known by different names. A gradual southward thinning in the beds of the Clear Fork and Blaine is shown both by the areal distribution of the formations and a comparison of the measured sections. Aside from its use in areal geology the map will be helpful in subsurface correlations in that it will show the approximate position in the geologic section of the starting point of any wells or tests within its boundaries.

INTRODUCTION

Within the next few years a somewhat intensive search for oil will probably be made throughout the Permian basin of West Texas, and especially in the northeastern portion, where as yet little development has taken place. When drilling is done in this area, the beds which crop out on the eastern side of the basin will necessarily be studied rather closely as an aid to subsurface correlations.

This paper and accompanying charts represent a compilation showing the major subdivisions and some of the more important individual members of the Permian in the area between the Cretaceous overlap in Nolan and Taylor counties and Red River. The map presented (Plate 9) has been made from outcrop data furnished by many company and independent geologists aside from the field work done by the writers. No originality is claimed for any of the subdivisions made, as all the formations and most of the individual members have been described previously, but information from different sources has been consolidated to show where certain beds crop out, and general designations have been given to

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, March 28, 1929. Published by permission of F. H. Lahee, chief geologist, Sun Oil Company.

[2]Geologists, Sun Oil Company.

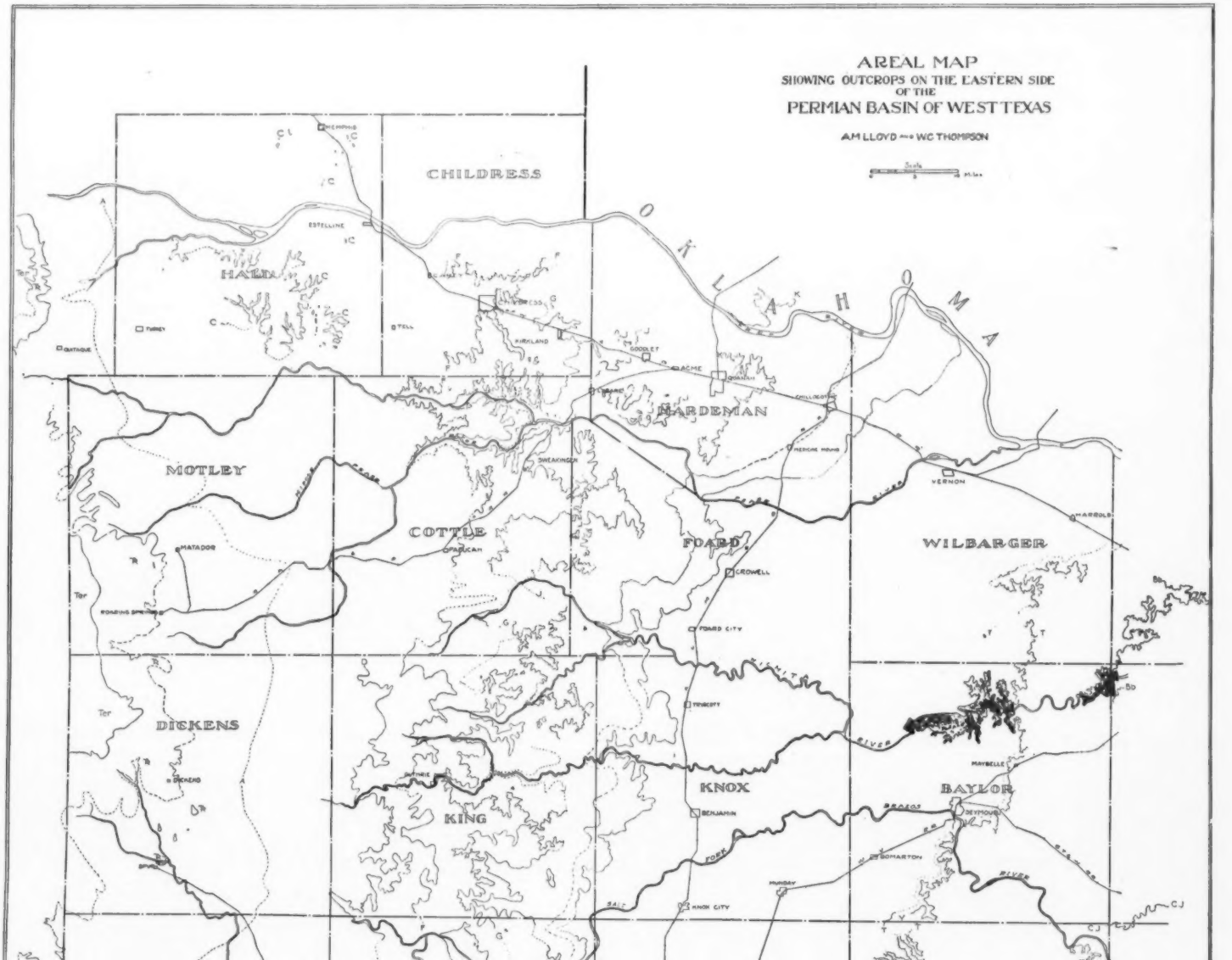
those known by several local names. Oklahoma terms for the larger subdivisions have been carried through into Texas in order to avoid duplication of nomenclature as far as possible.

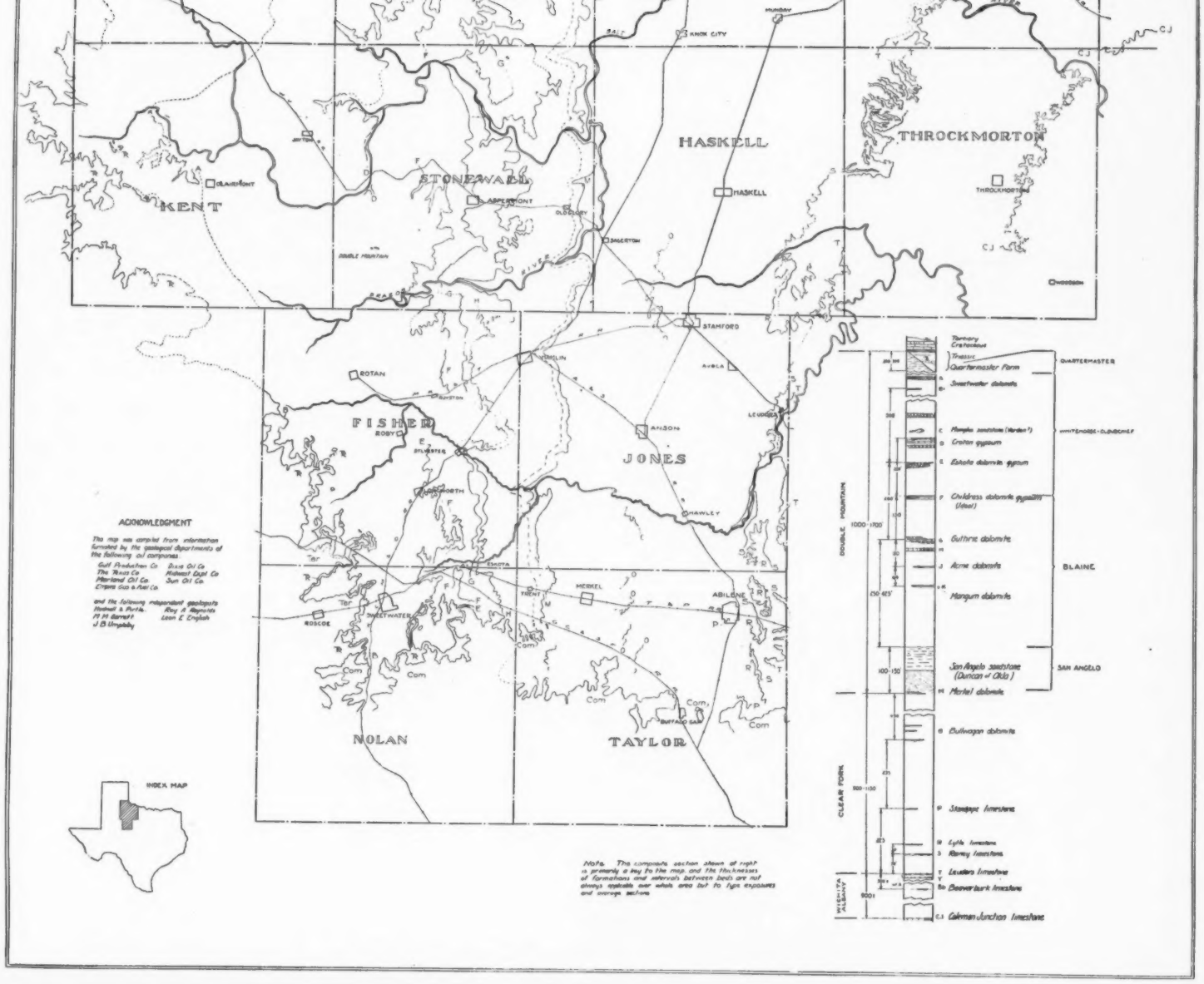
Greater emphasis has been placed on the Double Mountain group, or the upper half of the Permian, than on the Wichita-Albany and Clear Fork, on account of more personal familiarity with the former subdivision and because of several complex sedimentary conditions in the latter. Beds of the lower Permian change laterally from non-marine in the counties adjacent to Red River to marine a little farther south. A section of the Wichita-Albany through Archer, Wichita, and Wilbarger counties would show red beds, sand, and a few thin limes, and a similar section through Shackelford and Taylor counties would show practically all limes and shale with little sand. A detailed paper on the Wichita-Albany and Clear Fork would not be complete without a full consideration of these sedimentary changes and a subdivision of the beds as they extend southward. The writers have had neither sufficient time nor sufficient previous experience with the latter groups to attempt this phase of the problem.

Acknowledgments.—In presenting a paper of this sort it is difficult to give credit to all with whom ideas and data have been exchanged, but the writers especially desire to acknowledge the valuable assistance of the following men of geological departments of oil companies: H. B. Fuqua and W. R. Vance of the Gulf Production Company; F. C. Sealey, J. H. Markley, Jr., and Donald Kelly of The Texas Company; P. W. McFarland and L. W. Storm of the Sun Oil Company; W. J. Nolte and P. A. Meyers of the Marland Oil Company; A. C. Bace, R. B. Grigsby, and E. T. Bullard of the Dixie Oil Company; H. T. Morley of the Midwest Exploration Company; and A. R. Kautz of the Empire Gas & Fuel Company; Hudnall & Pirtle, Roy A. Reynolds, M. M. Garrett, Leon English, and F. H. Lahee, for suggestions and a criticism of the manuscript.

WICHITA-ALBANY GROUP

The section of the Wichita-Albany is shown in this subdivision to represent all beds between the Coleman Junction and Leuders limestones. Use of the Leuders limestone as a division between the Wichita-Albany and the overlying Clear Fork group is not based on paleontologic evidence, and, as far as lithology is concerned, the division might be placed at any of several lime beds in the section 100 or 200 feet above the Leuders. However, the latter is probably the thickest and most prominent of the series near its type locality, and as the Leuders and beds imme-


AREAL MAP
SHOWING OUTCROPS ON THE EASTERN SIDE
OF THE
PERMIAN BASIN OF WEST TEXAS
A.M. LLOYD — W.C. THOMPSON
CHILDRESS
OKLAHOMA
HALL
HARDEMAN
MOTLEY
COTTLE
FOARD
WILBARGER
DICKENS
KING
KNOX
BAYLOR
MATADOR
CROWELL
VERNON
QUANAH
ACME
GOODLET
ESTELLINE
TURKEY
TELL
MEMPHIS
SWEETWATER
ROSCOE
ROBY
ROTAN
HASKELL
STAMFORD
ABILENE
ANSON
JAYTON
KNOX CITY
BENJAMIN
SEYMOUR
MARTIN
MAYBELL
CHILLICOTHE
MEDICINE MOUND
MARGOLD
FOARD CITY
TRUSCOTT
DICKENS
SPUR
GUTHRIE
PADUCAH
ROARING SPRINGS
RED RIVER
BRAZOS
WICHITA
SALT FORK
PEASE RIVER
MILES


KENT
STONEWALL
HASKELL
THROCKMORTON
FISHER
JONES
NOLAN
TAYLOR
STAMFORD
ROTAN
ANSON
ABILENE
SWEETWATER
ROSCOE
MERKEL
HAWLEY
HASKELL
THROCKMORTON
KNOX CITY
ACKNOWLEDGMENT
This map was compiled from information furnished by the geological departments of the following oil companies
Gulf Production Co
The Texas Co
Mainland Oil Co
Empire Gas & Fuel Co
Dixie Oil Co
Midwest Expl Co
Sun Oil Co
and the following independent geologists
Hodnett & Purtle
H H Garrett
J B Umpleby
Roy A Reynolds
Leon E English
INDEX MAP
Note. The composite section shown at right is primarily a key to the map, and the thicknesses of formations and intervals between beds are not always applicable over whole area but to type exposures and average sections
Tertiary
Cretaceous
Triassic
Quartermaster Formn
Sweetwater dolomite
Mangum sandstone (Vernon?)
Croton gyp sum
Estacado dolomite gypsum
Childress dolomite gypsum (Ideal)
Guthrie dolomite
Acme dolomite
Mangum dolomite
San Angelo sandstone (Duncan of Okla)
Merkel dolomite
Bullwagon dolomite
Standpipe limestone
Lytle limestone
Harvey limestone
Lueders limestone
Beaverbank limestone
Coleman Junction limestone
QUARTERMASTER
WHITEHORSE-CLOUDCHIEF
BLAINE
SAN ANGELO
DOUBLE MOUNTAIN
CLEAR FORK
WICHITA ALBANY
1000-1700
920-1150
9001

diately adjacent to it seem to have a greater extent from north to south, the division was made here.

As already mentioned, the Wichita-Albany group is chiefly noticeable on account of the complete change from a non-marine "Red-bed" series along Red River, to a marine lime and shale section in Throckmorton and Shackelford counties. Scarcity of outcrops in the Red River area prevents measurement of a surface section, but sections shown in well logs indicate a thickness of approximately 900 feet and this corresponds with the measured surface sections of the southern area (Fig. 1).[1]

Beaverburk limestone.—The only member of the Wichita-Albany that extends north to the Red River counties is the Beaverburk, a brown to gray limestone 1-2 feet thick. This member crops out in southwestern Wichita County but grades into "Red-beds" a short distance west of Iowa Park. Undoubtedly it is equivalent to some of the limestone beds in southern Baylor County that extend southward, but intervening topography prevents its being traced.

CLEAR FORK GROUP

The Clear Fork group is predominantly a Red-bed section throughout the area under consideration. As in the case of the Wichita-Albany, the surface beds are such that good measured sections of the outcrops are not feasible, but data from wells and core drill holes give a fair idea of thickness. In the southern section along the Texas and Pacific Railroad, the thickness of the Clear Fork is approximately 900 feet, and this gradually thickens northward to about 1,150 feet in the Red River area. This formation produces a flat, featureless topography except in the eroded areas along the larger streams, where "bad lands" of red shales with narrow bands of white sandy shale and thin sandstones result.

Aside from a few thin limestones and dolomites in the Abilene area, there are no distinct horizons in the Clear Fork that can be traced any considerable distance. In his section along the T. & P. Railroad, Wrather[2] shows the Buffalo Hills above the Leuders. This does not seem to be a scarp-forming bed, except possibly in very local areas, but a sandy belt does occur at approximately this horizon and may be present from south to north throughout the Clear Fork outcrop. No definite ledges occur, but

[1]The vertical measurements given in these sections represent the thickness of outcrops. These figures should not be relied upon, except in a general way, for intervals between beds in areas some distance from their outcrop, as in most cases the intervals increase materially.

[2]W. E. Wrather, "Notes on the Texas Permian," *Bull. SW. Assoc. Petrol. Geol.*, Vol. 1 (1917).

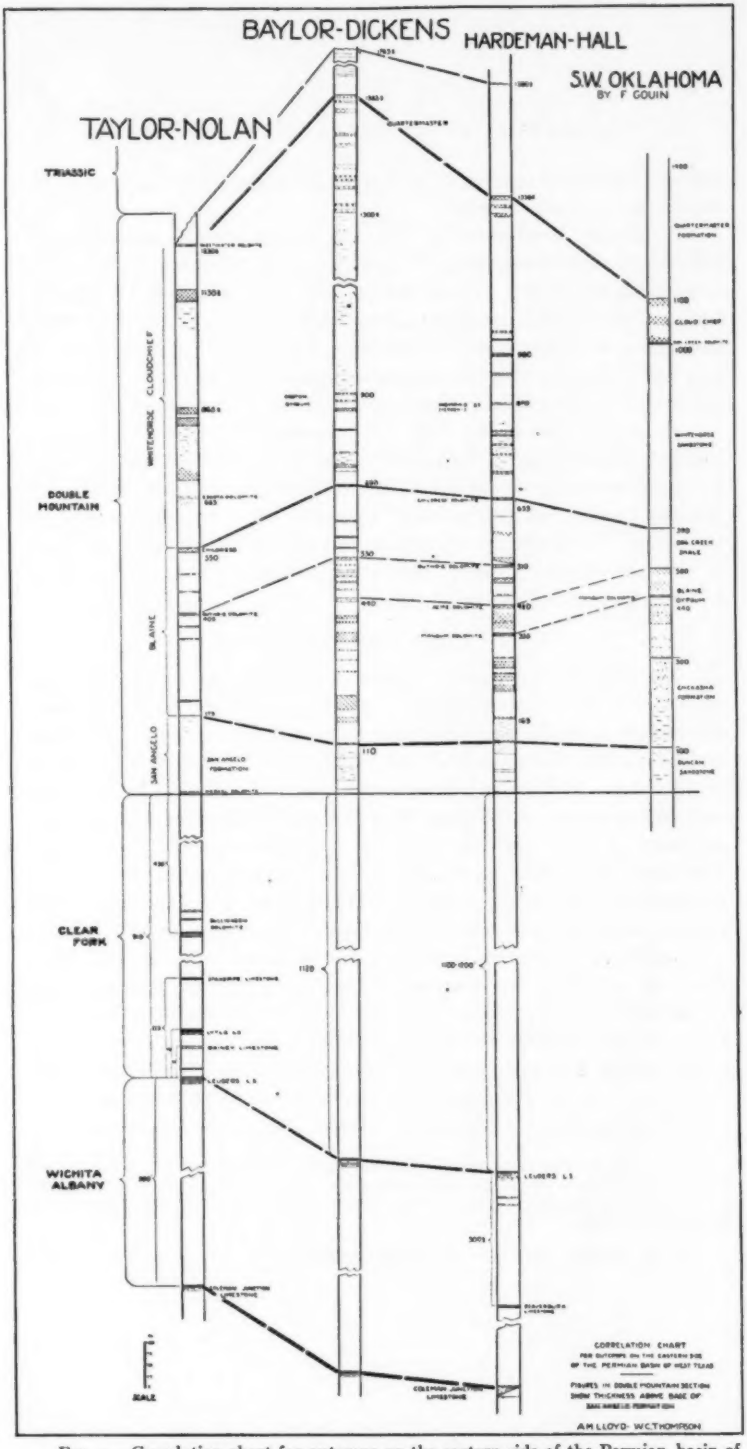


FIG. 1.—Correlation chart for outcrops on the eastern side of the Permian basin of West Texas. Figures in Double Mountain section show thickness above base of San Angelo formation, in feet.

a sandy soil and a large amount of loose sand on the surface indicate a sandy phase of the section. This condition is noticeable particularly west of Vernon, in Wilbarger County, and in eastern Knox and central Haskell counties.

Figure 1 shows the position of several thin limestones, namely, the Rainey, Lytle, and Standpipe, immediately above the Leuders. Of these the Rainey limestone is the only formation that has been traced farther than the vicinity of Abilene. This formation has been followed at least as far north as eastern Haskell County and may be present as a thin stringer as far as southern Baylor County. The Standpipe limestone, noticeable chiefly on account of its outcrop in the southwestern part of the city of Abilene, the Lytle, and possibly other beds not mentioned, have only a local extent and are not of sufficient importance to warrant further discussion.

Bull Wagon dolomite.—The Bull Wagon dolomite series occurs about the middle of the Clear Fork section in the Abilene area, and consists of several beds of white to gray dolomite ranging from a few inches to 18 inches in thickness, occupying approximately 50 feet of section. Outcrops of this horizon are scattered and erratic, but, from their position in the section, may be traced northward into southern Haskell County. Possibly some of the thin platy beds seen in the "bad lands" of Knox and Foard counties may represent this limy phase, but none of them covers sufficient area to make it individually important.

Merkel dolomite.—The Merkel[1] dolomite, top member of the Clear Fork, is a prominent bed for a limited distance beginning south of the Texas and Pacific Railroad, between the towns of Trent and Merkel in Taylor County, and extending to a point in eastern Stonewall County a few miles northeast of the town of Old Glory. It ordinarily consists of a light blue to gray dolomite ranging from 1 foot to 2 feet in thickness, or two members not more than 2 feet thick, separated by a thin shale break. As in the case of the Bull Wagon dolomite, the stratigraphic position of the Merkel after it pinches out northward is commonly represented by thin dolomitic beds. Such conditions can be seen in Foard and Hardeman counties, but the beds do not form benches or extend any considerable distance.

DOUBLE MOUNTAIN

Cummins[2] first described the Double Mountain group and named it for a very prominent topographic feature of southwestern Stonewall

[1]W. E. Wrather, *op. cit.*

[2]W. F. Cummins, *Geol. Survey of Texas 1st Ann. Rept.* (1890).

County. For a number of years, different authors have recognized and called attention to a correlation between certain beds of the upper Permian in western Oklahoma and the Double Mountain formation of Texas. Wrather[1] called attention to a possible correlation of the Whitehorse sandstone of Oklahoma with the Lake Trammel sandstone of his Abilene-Sweetwater section in 1917. Beede was probably the first to correlate the San Angelo sandstone with the Duncan sandstone of Oklahoma and also to recognize the relationships of other beds above this formation. In 1926 Gould[2] published a paper and a map showing some of the broader correlations between Kansas, Oklahoma, and Texas. Although the Double Mountain of Texas is considerably thicker than the aggregate of the Oklahoma formations which comprise it, there is a marked similarity in many of the subdivisions that makes a general correlation fairly easy.

SAN ANGELO FORMATION

The San Angelo formation has been described in some detail by Beede,[3] who traced it from San Angelo in Tom Green County to Red River, and subsequently into Oklahoma. For further details the reader is referred to his work. This formation almost everywhere is represented by pronounced scarps and forms a most valuable reference point for surface stratigraphy in the general region of its outcrop.

BLAINE FORMATION

As described in this paper, the Blaine formation contains considerably more than the Oklahoma section. The terms "Chickasha formation" and "Dog Creek shales" are not used because the equivalents of these members in Texas, although recognizable in most places, are not especially outstanding. Those beds between the San Angelo formation and the Whitehorse sandstone have been included in the Blaine, as all are similar and obviously belong together. The southwestern Oklahoma section of the Blaine commences approximately 200 feet above the Duncan sandstone, and the top is represented by the Acme gypsum of the Texas section.

[1]W. E. Wrather, *op. cit.*

[2]C. N. Gould, "The Correlation of the Permian of Kansas, Oklahoma, and North Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (February, 1926), p. 144.

[3]J. W. Beede and D. D. Christner, "The San Angelo Formation, The Geology of Foard County," *Univ. of Texas Bull. 2607* (1926).

The areal map (Plate 9) shows a wide belt of the Blaine in Hardeman and Childress counties, which converges to a narrow strip in western Taylor and eastern Nolan counties, due to an appreciable thinning of the southern section, the latter measuring about 375 feet, although the thickness in Hardeman and Childress counties is almost 600 feet. Aside from the thicker section, the dip of the beds in the northern area is abnormally low, and this naturally tends to widen the outcrop.

Throughout nearly all of its outcrop, the Blaine section is recognizable by a rough, hilly topography, covered with a heavy growth of stunted cedar trees. Beds of heavy gypsum intercalated with thin beds of red and blue shale comprise most of the formation, and the thicker shale beds are ordinarily gypsiferous and contain thin laminae of gypsum and satin spar.

Among the many gypsum and dolomite beds of the Blaine are several that can be traced almost the entire distance from Red River to the Cretaceous overlap. The outcrops shown on the areal map are by no means the only mappable units but are the most prominent, and are sufficiently close together to make useful reference points for stratigraphic and structural work.

Mangum dolomite.—In order to make additional correlations with the Oklahoma formation, the Mangum dolomite has been shown for a short distance across Hardeman County and southwestward. This bed crops out at Mangum, the county seat of Greer County, Oklahoma, and is a well marked horizon as far as followed into Texas. The Mangum member might be traced farther but its proximity to other beds that have been mapped makes this unnecessary.

Acme dolomite.—Above the Mangum, the first prominent dolomite is a series of several beds, ranging from 1 foot to 6 feet in thickness, which has been called the Acme from its type exposure in Hardeman County, where thick beds of gypsum, below the dolomite, are mined. The Acme is traced southward to Stonewall County and may be correlated with reasonable certainty with the McCaully beds of Fisher County.

Guthrie dolomite.—The Guthrie dolomite represents the top of the main gypsum series of the Blaine and forms an excellent marker through all the area covered. It ranges from 2 to 10 feet in thickness and in some places is entirely replaced by the gypsum beds which occur immediately above or below it. The Guthrie member may be followed from the vicinity of Kirkland in Childress County southward through its type locality in the bed of the south fork of Wichita River, at Guthrie in King County.

Plate 9 and Figure 1 show a bed (*H*) between the Guthrie and Acme which is about 30 feet below the former. The trace of this bed has been shown in Fisher County and southward to the place where it passes beneath Cretaceous rocks, since the Guthrie does not extend the entire distance.

Childress dolomite.—A gypsum and dolomite bed not more than 2 feet thick, 150 feet above the Guthrie member, is called the Childress dolomite, from its outcrops in and around Childress in Childress County. It can be followed southward to Nolan County, the only extensive gaps being an area of windblown sand in northern Stonewall County and north-central Fisher County. In central Stonewall County it forms the escarpment west of Aspermont, and is composed of a bed of blocky gypsum which changes laterally into dolomite and farther south is replaced by a gypsum bed which has been referred to locally as the Ideal gypsum.

It has been considered advisable to use the Childress dolomite as a dividing line between the Blaine and Whitehorse formations, as it is the best marker near the stratigraphic change. Subsequent reference is made to the rise in the section of lower Whitehorse sands, but the Childress member is sufficiently near both phases to serve as a marker.

WHITEHORSE-CLOUD CHIEF FORMATION

The Whitehorse sandstone and Cloud Chief gypsum are grouped together as one formation on the areal map and columnar sections, as no distinct break between the two is apparent in the area covered. In Childress and Hall counties, sandy beds similar to Whitehorse may be recognized 40 or 50 feet below the Childress bed, but southward shale beds replace the sandy horizon which is found higher in the section. Along Red River the Whitehorse member is a soft red friable sandstone and sandy shale with several gypsum beds. Typical Whitehorse may be seen west of Aspermont in Stonewall County and also south of Sweetwater, where the outcrops of Wrather's[1] Lake Trammel sandstone (now correlated with Whitehorse) occur. This section is best recognized by the broad, rolling hills cut by steep gullies whose sides stand vertically as high as 30 feet. Gypsum beds are prominent in this section in Texas.

Immediately below the Quartermaster formation is a section consisting of 250 feet of thick gypsum interbedded with red gypsiferous shale similar to Oklahoma Cloud Chief. Taken together, the Whitehorse and Cloud Chief members have a thickness of about 900 feet in the central part of the area discussed; northward and southward they thin to approximately 700 feet. The increased thickness of these members over

[1] W. E. Wrather, *op. cit.*

the combined thickness of the Oklahoma members is probably partly represented in both formations, as the beds between typical Whitehorse and typical Cloud Chief have some of the characteristics of each, and no definite break has yet been found.

Eskota gypsum.—The Eskota gypsum[1] and dolomite member occurs approximately 120 feet above the Childress bed in northern Nolan County, and consists of 10-20 feet of massive gypsum beds overlying a thin dolomite. The Eskota is undoubtedly equivalent to some of the gypsums in the northern part of the area, but it has not been followed farther than central Fisher County.

Memphis sandstone.—A fossiliferous limy pink to red sandstone is present in Hall County approximately 250 feet above the base of the Whitehorse sandstone. Although similar in appearance to the Verden "channel" sandstone of Oklahoma,[2] the authors have called this bed the Memphis sandstone, from the buttes formed by it near the county seat of Hall County. The Memphis sandstone ranges from 3 to 10 feet in thickness and, as already mentioned, is similar in general characteristics to the Verden except that it crops out in a belt 10 or 12 miles wide and is much higher in the geologic section, the Oklahoma member being in the upper part of the Dog Creek shale.[3] The most southerly outcrop of this bed is in northern Motley County near the town of Northfield.

Sweetwater dolomite.—In southwestern Fisher county and northern Nolan County, directly below the Triassic beds, is a thin persistent dolomite, in places fine-grained and sandy and in places coarsely crystalline, ranging from 1 foot to 3 feet in thickness. This bed strikes N. 30° W. through the city of Sweetwater and is named after its outcrop there.

QUARTERMASTER FORMATION

The Quartermaster formation of Texas is exposed at separated localities immediately below the escarpment of Triassic and younger beds. It consists of 200-300 feet of thin red sands and sandy shales with gypsiferous shales toward its base, showing an excellent stratification in marked contrast to the Permian immediately below it. Outcrops are ordinarily much slumped, probably from the solution of gypsum beds below. Although exposures are not continuous, this formation may be traced on account of its lithologic characteristics and position in the

[1] W. E. Wrather, *op. cit.*

[2] R. R. Reed and N. Meland, *Jour. Geol.*, Vol. 32 (1924), pp. 150-67.

[3] C. N. Gould, "Index to the Stratigraphy of Oklahoma," *Oklahoma Geol. Survey Bull. 35*, p. 92.

geologic section from Hall County southward into Kent County, the eastern overlap of Triassic beds obscuring it farther south. Noteworthy occurrences are in Dickens County immediately east of Dickens, in eastern Briscoe County, and in the Double Mountains of Stonewall County.

OVERLAPPING FORMATIONS

Although not a part of this discussion, the Triassic and Cretaceous beds deserve brief mention here as the southern and western boundaries of the Permian outcrops in the area described in this paper.

The Triassic is readily distinguishable from the Permian in this region, inasmuch as the sands of the former have a characteristic gray to yellow color and are ordinarily highly micaceous, the basal part in many places being conglomeratic and containing fossil wood. The Triassic lies unconformably on beds of Whitehorse and Quartermaster age.

The Cretaceous is present in the prominent mesas of the Callahan divide in Callahan, Nolan, and Taylor counties, and lies unconformably across the whole Permian section. Beds ranging from Trinity to Edwards limestone are present in the Callahan divide as well as on Double Mountain.

DISCUSSION

CHARLES N. GOULD, Norman, Oklahoma: The authors of this paper are to be congratulated on their very clear and concise presentation of the subject. The only criticism that I would make is in the matter of nomenclature. If I understand it correctly, you are including under the term Blaine of Texas the formations which, farther north, in Oklahoma and Kansas, include the Flower Pot, or Chickasha, below the Blaine, and the Dog Creek above the Blaine. In other words, the Blaine of Texas, as you are now considering it, includes everything from the San Angelo, or Duncan, up to the Whitehorse above. Is this correct?

W. C. THOMPSON: That is correct.

CHARLES N. GOULD: The point I wish to make is this. It is generally considered good nomenclatural practice, whenever a formation is modified, either by adding to it or taking from it, that a new name be used. It is quite probable, as has been suggested, that neither the Chickasha nor the Dog Creek can be differentiated in Texas. But inasmuch as the term Blaine, as described in this paper, includes also the equivalents of the Chickasha and Dog Creek of Oklahoma and Kansas, a new term should be used in Texas. Otherwise, if the term is used in two different senses in the different states, geologists will soon be speaking of Gould's Blaine and Thompson's Blaine.

Another point I wish to bring out is the matter of the "channel" sandstones. We now know of three localities in the Red-beds of Oklahoma and

Texas where the so-called "channel" sandstones occur. One locality is the type Verden in Grady and Caddo counties, extending north into Canadian County and possibly connecting with the Greenfield dolomite in Blaine County. The second locality is in Woods and Woodward counties, Oklahoma, extending from Whitehorse Buttes, near the Kansas line, southwest past Wildcat Buttes, crossing Cimarron River into Woodward County. The third locality is in Texas, extending from the vicinity of Shamrock southwest past Memphis and Estelline into Motley County. All of these "channel" sandstones are, I believe, in the Whitehorse. Their origin has never been definitely determined. I am very much hoping that further studies by Mr. Thompson and others will help to clear up this point.

ROY H. HALL, Wichita, Kansas: Is it not true that much of the confusion in our correlation of Permian formations from one widely separated area to another is due to basinward changes in the character of the formations themselves?

CHARLES N. GOULD: Yes, I think many of the mistakes made in the past have been due to widely separated observations.

R. W. SAWYER, Oklahoma City, Oklahoma: The finding of sandstones, similar to the Verden sandstone, in the Whitehorse of Texas, corresponds with work in Oklahoma. The state geologic map of Oklahoma is in error in that it shows the Verden sandstone to be in the Dog Creek shale, in the Chickasha area. In Sec. 22, T. 7 N., R. 8 W., there is a bed similar to the Verden, but much thinner. It is about 70 feet below the Verden, and directly above the base of the Whitehorse.

CLYDE M. BECKER, Chickasha, Oklahoma: If the fact is given recognition that the top of the Chickasha of Oklahoma is correlated in time with the top of the Dog Creek of Kansas and the red shales above the Blaine and below the Whitehorse of Texas, and that the base of the Duncan of Oklahoma is correlated with the base of the Flower Pot of Kansas and of the San Angelo of Texas, and that the Dog Creek, Blaine, and Flower Pot are only a basinward change in the lithology of the Chickasha-Duncan sandstone, all this confusion in correlating will be eliminated. The fact that the Chickasha-Duncan grades laterally into the Dog Creek, Blaine, and Flower Pot and has the same time equivalent is now recognized by every field geologist who has detailed the entire region. At a meeting of geologists in Chickasha at which were present Sherwood Buckstaff and H. F. Schweer of the Shell, L. D. Bartell and E. O. Buck of the Skelly, N. V. Potter and O. C. Clifford, Jr., of the I. T. I. O., Brown of the Gypsy, Fulton and Wells of the Becker-Reed Oil & Gas Company, and myself, we agreed on these facts and suggested the name of El Reno formation for beds of the Chickasha-Duncan time equivalent which would include all the beds from the top of the Hennessy shale to the base of the lower member of the Whitehorse sandstone.

GEORGE H. NORTON, Tulsa, Oklahoma: This paper is regarded as an important contribution to our knowledge of the Permian Red-bed stratigraphy of Texas. The more so if, as Dr. Gould suggests, the name Blaine be limited, in

Texas, to include only those beds which may be correlated with the Blaine gypsum beds of Oklahoma.

The writer notes that the Guthrie dolomite has been correlated with a dolomite which has been known locally as the Aspermont dolomite, whereas it is the opinion expressed by other geologists that the Guthrie dolomite underlies the dolomite so well exposed at Aspermont, forming the next lower prominent scarp. The writer has no data on which to base an opinion in this matter.

However, the writer believes that the authors have fallen into error in their correlation of the Nolan County-Taylor County section with those farther north. Intermittently since 1923 the writer has worked in the field in this area on this problem, and he feels very certain that the Eskota dolomite and the gypsum-anhydrite series immediately overlying it are to be found in the strata underlying the dolomite locally called the Aspermont dolomite, approximately 100 feet below. In support of this opinion the following brief sections are given:

Section Exposed at U. S. Gypsum Company Plant, Sweetwater, Nolan County, Texas		Section Exposed at Prominent Scarp East of Aspermont-Hamlin road About 8 Miles North of Hamlin, Texas	
Feet		*Feet*	
		4	Dolomite (Aspermont)
		45	Shale and thin gypsum
	Poorly exposed Red-beds	18	Gypsum and shale, interbedded
17	Gypsum, phenocrystalline*	7	Gypsum, phenocrystalline
1	Sandstone, gray, gypseous	1	Sandstone, gray, gypseous
2	Shale, red, gypseous	2	Shale, gray
2½	Gypsum	4	Shale, red
3	Shale, red	2	Dolomite, gypseous
2	Gypsum, very white,—terra alba	3	Gypsum, very white,—terra alba
1	Shale and sandstone, red	3	Impure gypsum, and shale, red
10	Gypsum, phenocrystalline	6	Gypsum, phenocrystalline
½	Dolomite, ripple-marked Eskota	¼	Dolomite, weak, soft
20	Red and gray sandstones	6	Shale, red and gray
		½	Dolomite, weak
		6	Shale, red, and gypsum beds
		2	Dolomite, not prominent
		65	Interval, approximate
		4	Dolomite, prominent scarp

*Correlate beds underscored.

The writer believes that the correlation based on these gypsum beds and associated dolomite and sandstone layers is the key to the proper correlation of the northern sections with the Nolan County-Taylor County section. If this correlation is made, the gypsum series immediately above the Eskota dolomite, the important commercial deposits of Nolan County, Texas, can probably be correlated with the economically important beds of the Blaine in Oklahoma.

PERMIAN STRATIGRAPHY AND STRUCTURE OF PARTS OF SOUTHEASTERN NEW MEXICO AND SOUTHWESTERN TEXAS[1]

W. GRANT BLANCHARD, JR.[2], and MORGAN J. DAVIS[3]
Dallas, Texas, and Roswell, New Mexico

ABSTRACT

The Permian stratigraphy of southeast New Mexico and northern trans-Pecos Texas displays abrupt changes in lithology and fauna. Interpretations concerning relationships in the Sacramento, Hueco, Sierra Diablo, Guadalupe, Delaware, and Apache mountains are presented. The Sacramento and Hueco mountains reveal rocks of lowest Permian age, resting unconformably upon the Magdalena formation of upper Pennsylvanian age.

The Chupadera formation of New Mexico is separated partly from the greater part of the Guadalupian by a topographical and structural feature, called the Bone Springs arch. Reef-building agencies adjacent to and upon the arch had a profound effect upon the lithology of the upper Delaware Mountain formation and younger strata. The Capitan is, in reality, the dolomitic phase of the upper Delaware Mountain formation and the Carlsbad formation. On the surface the reef fringe extends from Guadalupe Point to Carlsbad, New Mexico; thence, by subsurface data, its presence is indicated through southeastern New Mexico and part of the West Texas Permian salt basin, defining the north, east, and south limits of the Delaware Mountain "sand" basin.

Oil pools of large size are located near the reef fringe in Winkler County, Texas, and parts of Lea and Eddy counties, New Mexico; accumulation is probably the result of exceptional conditions of sedimentation and structure.

INTRODUCTION

The work of mapping and correlating the Permian of trans-Pecos Texas and southeastern New Mexico was undertaken primarily to assist in determining subsurface conditions in investigations relative to the oil and gas possibilities of the Permian salt basin.

Much excellent work has been done in this area, and there is here no attempt to improve on this earlier work, except where the writers have been forced to different conclusions by detailed work. Some heretofore unpublished points will be mentioned, as well as some features that have been described but their general relation to the area not definitely

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, April 1, 1929. Published by permission of the Marland Oil Company and the Humble Oil and Refining Company.

[2]Formerly geologist for the Marland Oil Company.

[3]Geologist, Humble Oil and Refining Company.

shown. The present paper was undertaken in the hope that a more coherent picture of the whole region could be presented.

It is a pleasure to acknowledge the willing assistance of the geologists in the several districts. Their suggestions and ideas have been found valuable and stimulating.

The writers are particularly indebted to Alex W. McCoy, Wallace E. Pratt, W. A. J. M. van der Gracht, and J. W. Beede for their discussions on field trips; to I. A. Keyte for his paleontological data; to Harry L. Baldwin and C. L. Mohr, who assisted the senior writer in field work covering a period of nearly two years; to Vaughn C. Maley, who furnished the junior writer much valuable data on the Apache Mountains area; and to Franklin S. Prout for many helpful suggestions and criticisms.

Regional Physiography and Structure

The region under discussion may be divided into three provinces. The first includes the mountainous areas covered by the Sacramento-Hueco mountains, the Guadalupe-Delaware-Apache mountains, and the Sierra Diablo Mountains. The second is occupied by the Pecos Valley. The third embraces the Llano Estacado, those great flat plains lying east of the Pecos Valley.

The mountainous province is occupied largely by great geanticlines that have collapsed along their axes and are arranged *en échelon*. Axial downthrown blocks form bolson and salt flats and the upthrown limbs cause the steep escarpments which constitute the mountain ranges.

The eastward-dipping Sacramento-Hueco mountains are an eastern limb of such a geanticline separated by Tularosa Basin from the western limb, which is made up of the San Andres-Organ-Franklin chain of westward-dipping mountains.

The strata approximately 10 miles east of the Hueco Mountains escarpment become comparatively flat, in a low-dipping syncline which separates the Hueco Mountains from the Sierra Diablo Mountains (also known as Sierra Diablo Plateau). The gently westward-dipping strata of the Delaware Mountains, the east limb of a geanticline, is an exact replica of structural conditions described above. The two ranges are separated by a *graben* known as Salt Flats. The displacement on the west side of the *graben* appears to diminish more rapidly toward the north than that on the east side. At Los Alamos (the Cottonwoods), the throw is less than it is at El Capitan Peak, approximately 20 miles northeast. These faults almost die out at the north end of Salt Flats, locally known as Crow Flats.

A considerable amount of vulcanism is associated with the uplifts. Prominent intrusives include Cerro Alto in the Huecos and the Cornudas at the north end of the Sierra Diablo Plateau. An intrusion is found in Marble Canyon in the northern part of the Sierra Diablo escarpment and a dike has been noted northeast of Guadalupe Point in T. 26 S., R. 24 E., Eddy County, New Mexico.

The long cuesta that dips eastward from the Sacramento Mountains on the north, and the Guadalupe-Delaware mountains on the south, forms the western side of the Pecos Valley, the central physiographic province. The uppermost beds of the mountains dip under the surface near Pecos River, the chief drainage channel of this province.

Eastward the surface rises by stages through a zone of rolling country, showing sharp dissection in places, until the western rim of the Llano Estacado is reached. The high escarpment that marks the edge of these plains is 40-50 miles east of Pecos River. A cap rock of hard caliche holds the amazingly level surface of the plains. In its southern extension, the Llano Estacado all but loses its identity in the sand dunes so prevalent in the southeastern corner of New Mexico and adjacent parts of Texas.

Subsurface information reveals a regional easterly dip continuing from Pecos River into Texas, locally reversed by anticlinal folds which are located along certain trends throughout the Salt Basin (Plate 10).

Stratigraphy

The region under consideration displays many examples of sudden changes in fauna, lithology, and stratigraphic intervals. These anomalies often cause much difficulty in the correlation of two isolated areas of outcrops. Unless formations can be traced from one locality to the other, convincing proof regarding a proposed correlation is difficult to obtain.

The stratigraphy of the Hueco has been ably handled by J. W. Beede,[1] and that of the Glass Mountains has been covered by J. A. Udden,[2] P. B. King and R. E. King,[3] and Charles Schuchert.[4] Although the stratigraphy in these areas is not a part of this paper, the writers refer to them for purposes of correlation.

[1]J. W. Beede, "Geology and Oil Possibilities of Northern Diablo Plateau," *Univ. of Texas Bull. 1852* (1918).

[2]J. A. Udden, "Geology of the Glass Mountains," *Univ. of Texas Bull. 1753* (1917).

[3]P. B. and R. E. King, "The Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Univ. of Texas Bull. 2801*.

[4]Charles Schuchert, *Amer. Jour. Sci.*, 5th Series, Vol. 14 (November, 1927).

ABO FORMATION

The Abo formation is characterized by its dark red color. It consists, primarily, of coarse sandstones that in many localities are arkosic and conglomeratic. These sandstones are intercalated with dark shales and a few limestones which are gray and pink in color. In its type locality, Abo Canyon, at the south end of the Manzano Range, Terrance County, New Mexico, it is a coarse-grained sandstone, conglomeratic at the base, arkosic and shaly in places, and of a dominantly chocolate color. Its thickness here is more than 1,000 feet.

In the Texas Production Company's "Dunken dome" well in Sec. 29, T. 17 S., R. 18 E., Chaves County, New Mexico, the entire Abo section of 1,400 feet is mainly red sandstones and red sandy shales, although some dark shales and limestones were noticed.

SACRAMENTO MOUNTAINS

In the Sacramento Mountains the Abo rests unconformably upon the Magdalena (Pennsylvanian) throughout the length of the escarpment. Immeditely east of Tularosa the Abo section may be considered representative. Here beds of gypsum are found in the lower part of the formation. Near Owl Tanks (T. 25 S., R. 11 E., Otero County, New Mexico), the Abo thins out, but at this southernmost outcrop the formation retains the characteristics noticed farther north.

In Grapevine Canyon, near the southern end of the Sacramento escarpment, there is a series of gray limestone and reddish-gray shales which may be upper Abo in age. These beds have an important significance in a later discussion.

HUECO MOUNTAINS

At Owl Tanks, on account of the position of the Abo outcrop in the terrane, its relationship with the formations in the Hueco Mountains, a short distance southward, is extremely difficult to determine.

The "Manzano" group of Beede[1] occupies the greater part of the northern half of the Hueco Mountains escarpment. Although it can not be stated unreservedly, it is probable that only the lower 200 feet exposed in the Diablo scarp at Marble Canyon is equivalent to these beds, and it is believed they thicken rapidly southward to make up the "Permian" part of the Wylie Mountains. Thus from one locality to another only minor parts of the beds on the Hueco and Diablo escarpments are the same formation. It seems that there is a greater probability that this

[1] *Univ. of Texas Bull. 1852* (1918), p. 15.

rapid change in thickness represents a difference in the amount of synchronous deposition than that it is the result of removal of beds and subsequent deposition.

The "Manzano" group seems to be equivalent to the lower part of the Abo. This correlation is offered because both formations lie unconformably on the Magdalena, and occupy the same stratigraphic position with relation to upper formations.

GUADALUPE-DELAWARE MOUNTAINS

The Abo is not present in the Guadalupe-Delaware Mountains unless its upper part is represented by the Bone Springs limestone, a correlation that will be discussed later.

LEONARD FORMATION (BONE SPRINGS LIMESTONE)

For a detailed description of the Leonard in its type locality reference is made to works previously cited.

HUECO AND SIERRA DIABLO MOUNTAINS

In the Hueco Mountains near Shakespeare Tanks, Beede[1] reports conglomeratic beds which he questionably refers to the Leonard formation of the Glass Mountains section. Concerning these beds he says in part:

> It is not improbable that this conglomerate would overlie the whole Manzano group in the northern Huecos had it not been removed by erosion..... and apparently passes beneath higher Permian deposits in the region of Brackett Draw, on the west side of Salt Flats.

Beede does not designate the base of these conglomeratic beds in the Sierra Diablo escarpment. There are marked faunal differences between the "Manzano" group and the greater part of these beds in the northern part of the same escarpment. The writers believe that all but the lower 200 feet definitely assigned to the "Manzano" are Leonard.

Changes in thickness as previously noted in the "Manzano" also obtain in the Leonard. This further bears out the conception of rapidly shifting depositional conditions throughout the area.

In Apache Canyon, on the eastern side of the northern Sierra Diablos, the Leonard formation is 1,500 feet thick and can be divided into three members. The basal member, 650 feet thick (not exposed in the Guadalupe Mountains), is a gray massive limestone containing but few fossils other than crinoid stems. The medial part, 550 feet thick, is generally thinner bedded and almost black, the base being marked by a

[1] *Univ. of Texas Bull. 1852*, p. 22.

shale zone 30 feet thick. The upper member is lighter in color and much better bedded than the lower member, which it resembles somewhat. The middle and upper divisions are very fossiliferous. Large *meekellas* are particularly numerous besides many *producti* and *leptodi* in the vicinity of Victorio Peak. The medial member contains more fine-grained calcareous sands and shales. The uppermost beds in Apache Canyon are probably near the top of the Leonard formation, as they are overlain by Delaware Mountain sands near Brackett Draw.

GUADALUPE-DELAWARE MOUNTAINS

The age and correlation of the oldest rocks exposed along the west-facing escarpment of the Guadalupe Mountains are much discussed subjects among geologists. In all publications they have been referred to as the "Black lime" or "Basal black lime" and the lowest member of the Delaware Mountain formation.

The basal dark limestone series in the Guadalupe and Delaware mountains is here designated as the Bone Springs limestone, although its correlatives elsewhere will continue to be called the Leonard formation. The name, Bone Springs, is introduced because of the structural and depositional significance attached to the formation in the Guadalupe Mountains and eastward. It takes its name from the canyon of the same name opening in Sec. 2, Blk. 66, Culberson County, Texas. Numerous geologists working in the region at this time are acquainted with the term. The series will not here be included in the Delaware Mountain formation because of faunal difference, lithologic dissimilarities, and the angular unconformity that separates the two.

The limestone series, here called the Bone Springs limestone, is described by C. L. Baker[1] as being a black, shaly, "anthracolitic" limestone, generally occurring in beds ranging from 1 inch to 3 inches in thickness, although a few exposures show no bedding planes. An exceptional depositional feature is the seeming cross-bedding noticeable at many points in both black and gray phases along the Guadalupe scarp. This condition is well developed in the first canyon north of Bone Springs Canyon. Limestone that was deposited horizontally is overlain by beds of the same material dipping at angles as steep as 15°. This condition was described by C. L. Baker as thrust, but is regarded by the writers as being a purely depositional effect.

North of Bone Springs Canyon, a mass of hard gray hackly limestone, that evidently has been removed at Bone Springs Canyon,

[1] *Amer. Jour. Sci.*, 4th Series, Vol. 49 (1920), p. 126.

comes into the series. This section, approximately 750 feet thick, lies conformably on top of the black limestone. In Goat Seep Canyon, 2 miles north of Bone Springs Canyon, there is seemingly a gradational zone of dark gray limestone, marked by a fossiliferous horizon, which gives some evidence that the gray and black phases of this formation grade one into the other from point to point.

The total thickness of Bone Springs limestone exposed in the Guadalupe Mountains is approximately 1,600 feet. E. H. Sellards[1] states that the Bureau of Economic Geology of Texas, on the advice of J. W. Beede, considers that the Williams Ranch core test at Guadalupe Point which started near the top of the black limestone, exposed at that point, penetrated at least 2,500 feet of Leonard. Since the Goat Seep section has been removed at this point, the formation was very thick at the time of deposition.

At Bone Springs Canyon, the outcrop forms a ridge of hills which plunges south toward Guadalupe Point. These south dips are readily seen along the road between Ables, Texas, and Guadalupe Point. North of the canyon, the outcrop forms a prominent ledge, at the base of the Guadalupe scarp, and makes a rough precipitous cliff that ends abruptly at the foot of Flexure Canyon (4 miles south of the state line) as the result of a very steep west dip or flexure.

From Guadalupe Point, the Bone Springs limestone has been traced southward along the westward base of the Delaware Mountains for approximately 25 miles. Beede[2] measured a maximum thickness of 750 feet of Bone Springs limestone in his two Delaware Mountain sections.

In The Pure Oil Company's Quaid No. 1, Sec. 12, Blk. 63, Culberson County, nearly 2,000 feet of the formation was drilled.

The principal evidence for correlating the Bone Springs limestone of the Guadalupe Mountains and the beds referred to as Leonard in the Sierra Diablo Mountains, with the type Leonard in the Glass Mountains, Brewster County, Texas, is the similarity of fossils and lithology. It was hoped fossil lists from the Bone Springs limestone and the Leonard formation collected from the localities just referred to would be available at this time. I. A. Keyte has sent collections to G. H. Girty in Washington, D. C., but to date his identifications have not been forthcoming. However, from field studies Keyte believes the faunas to be the same.

[1]Personal communication.

[2]*Univ. of Texas Bull. 2346* (1923), Plate I.

As has been stated, in Brackett Draw, 4 miles west of the north end of the Sierra Diablo, Beede[1] reports Word(?) ammonites from beds which overlie strata that are here considered to be Leonard. The ammonite-bearing beds are considered by the writers to belong unquestionably in the Delaware Mountain formation. Thus, this exposure furnishes additional corroboration to the foregoing correlations between the Guadalupe-Sierra and Diablo-Glass mountains sections.

The possibility that the Leonard and upper Abo are equivalent should be noted at this time. If the limestones and shales mentioned in the Abo discussion as being present in Grapevine Canyon should be proved to be definitely Abo in age, it is possible that they may represent all that remains of the broader phase of the Leonard on the south and east. There is also another Leonard correlation that will be discussed in connection with the Yeso division of the Chupadera formation.

BONE SPRINGS ARCH

Before continuing the discussion of stratigraphy, it is thought advisable to describe a great structural arch that is displayed in cross section on the west face of the Guadalupe Mountains (Fig. 1 and Plate 11). A description of this feature, here designated as the Bone Springs arch, is given because of the belief that it has exercised a profound influence on the sedimentation above it.

It is desired to attach more importance to the unconformity at the top of the Bone Springs limestone than was formerly granted.

The mass of Bone Springs limestone which cuts out, because of nondeposition, more than 1,500 feet of Delaware Mountain sands and (though not exposed) probably equal amounts of Yeso sediments, is what is termed the Bone Springs arch. This feature, a structural and topographical ridge, controlled the limits of lower and middle Delaware Mountain and Yeso deposition and had a striking effect upon the lithology of the upper part of the Delaware Mountain formation.

Acting as a barrier, the arch restricted the Yeso sea, lying on the north, causing thick beds of gypsum to be deposited, while, contemporaneously, marine sandstones of the Delaware Mountain formation were being laid against the barrier on the south side.

GRAPEVINE CANYON SECTION

The Abo formation unconformably overlies 1,050 feet of the Magdelena formation at the southernmost mesa in the Sacramento Mountains, 10 miles east of Escondida, New Mexico.

[1] *Univ. of Texas Bull. 1852* (1918), p. 24.

The Abo formation was measured in Grapevine Canyon, 12 miles east of Escondida, New Mexico.

ABO FORMATION

Thickness in Feet	*Description*
22	Bluish-gray limestone and blue chert (capping lime of small outlier)
15	Concealed. Probably dark shale
10	Dark, thin limestones
15	Greenish-brown micaceous sandstone
33	Thin, well bedded dark gray, black and brown lime; cherty; fossiliferous
9	Brownish-gray lime; upper member reddish-brown
23	Purplish-gray and brown speckled sand, coarse
2	Brownish-gray "rotten" lime. Weathers brown
19	Soft, purplish-red sandstone and thin dark gray carbonaceous limes
33	Medium-grained, dark gray lime, irregular cherty lime fragments; fossiliferous; upper part finer-grained
10	Concealed. Probably limestone
14	Dark gray, fossiliferous limestone; contains carbonaceous material
41	Coarse, greenish-drab micaceous sandstone, more quartzitic near top
30	Concealed. Probably red shale or soft green sandstone
1	Coarse limestone conglomerate, small quartz pebbles; fossiliferous
15	Red sandy shale, reddish-purple, finely arkosic, micaceous sandstones

The following section was measured 2 miles farther up Grapevine Canyon. The first member of each section is the same limestone.

Thickness in Feet	*Description*
50	Massive gray and bluish-gray limestone; blue chert
37	Concealed
10	Brown and gray limestone
25	Concealed
8	Dark gray limestone; fossiliferous
35	Brownish-green, micaceous sandstone
2	Gray and brown limestone; fossiliferous
40	Brownish-green micaceous sandstone
26	Massive, dark gray limestone; fossiliferous; finer-grained near top
76	Red sandstone and shale at base, then greenish-brown sandstone

At one high point on the broad arch, 30 miles north of Guadalupe Point (Sec. 22, T. 24 S., R. 20 E.), no Yeso or Delaware Mountain sand was deposited and the San Andres limestone (upper Delaware equivalent) lies directly on the channeled surface of the Bone Springs limestone.

FIG. 1.—West-facing escarpment of the Guadalupe Mountains. Highest point on Bone Springs arch at left side of picture. *C*, Capitan; *D*, Delaware Mountain sandstone; *BS*, Bone Springs limestone.

Further reference to the Bone Springs arch will be made in a discussion of the limestone phase of the Delaware Mountain formation.

CHUPADERA FORMATION

The Chupadera formation of N. H. Darton[1] takes its name from its type locality at Chupadera Mesa in central New Mexico, where more than 1,500 feet of the formation is exposed. The majority of New Mexico geologists have found it convenient to recognize the old divisions of Lee and Girty,[2] who separated the formation into the Yeso formation and the San Andres limestone. Able descriptions of the Chupadera have been given by these authors.

YESO FORMATION

The Yeso division normally overlies the Abo. Ordinarily the two series display seeming conformity, although according to Keyte[3] there is an unconformity between them at places.

Generally the Yeso is made up of light red and yellow shales and gypsum beds with subordinate strata of sandstone and limestone, although locally the section contains much limestone and, in the northern part of New Mexico, much sandstone.

SACRAMENTO MOUNTAINS

Along the Sacramento escarpment the Yeso outcrop parallels that of the Abo in a broader belt above it. The upper part contains many fossiliferous limestones and shales and is capped by a saccharoidal, subangular, white to yellow-brown sandstone ranging from 20 to 60 feet in thickness, known among New Mexico geologists as the Glorieta sandstone. It is an easily recognized member both in the field and in the subsurface.

In the Texas Production Company's Dunken dome No. 1, previously referred to, drilled on the eastern cuesta of the Sacramento Mountains, the Yeso, including the Glorieta, was found to be more than 2,100 feet thick.

At the south end of the Sacramento Mountains and, in their southern continuation, along the escarpment that extends to the northern end of

[1] *U. S. Geol. Survey Bull. 726-E* (1922), p. 181.

[2] *U. S. Geol. Survey Bull. 389* (1909), p. 12.

[3] Personal communication.

the Hueco Mountains, the Yeso becomes predominantly a limestone and shale section losing practically all of the gypsum and most of the Red-beds found in it at Tularosa, New Mexico.

PECOS VALLEY AND LLANO ESTACADO

One of the most eastern exposures of the Glorieta occurs at the foot of Picacho Hill on Hondo River where the Roswell-Alamogordo road enters the Hondo Valley, Lincoln County, New Mexico.

The Yeso and the Glorieta are reached in wells east and northeast of Roswell, New Mexico, as far as the eastern state line. In this region, the Yeso contains varying amounts of salt and is separated from a higher salt series by the San Andres limestone that immediately overlies it.

In the Gibson Oil Company's Parks No. 1, Sec. 25, T. 8 N., R. 32 E., Quay County, New Mexico, the Glorieta horizon is represented by brown shale, salt, and brown sand.

GUADALUPE MOUNTAINS

The upper Yeso and Glorieta are exposed along the northern part of the west face of the Guadalupe Mountains from a locality 7½ miles north of Wilkerson's Ranch to the vicinity of Sec. 34, T. 23 S., R. 20 E., Otero County, New Mexico. Down-faulted San Andres limestone prevents the exposure from being followed farther south (Plate 10).

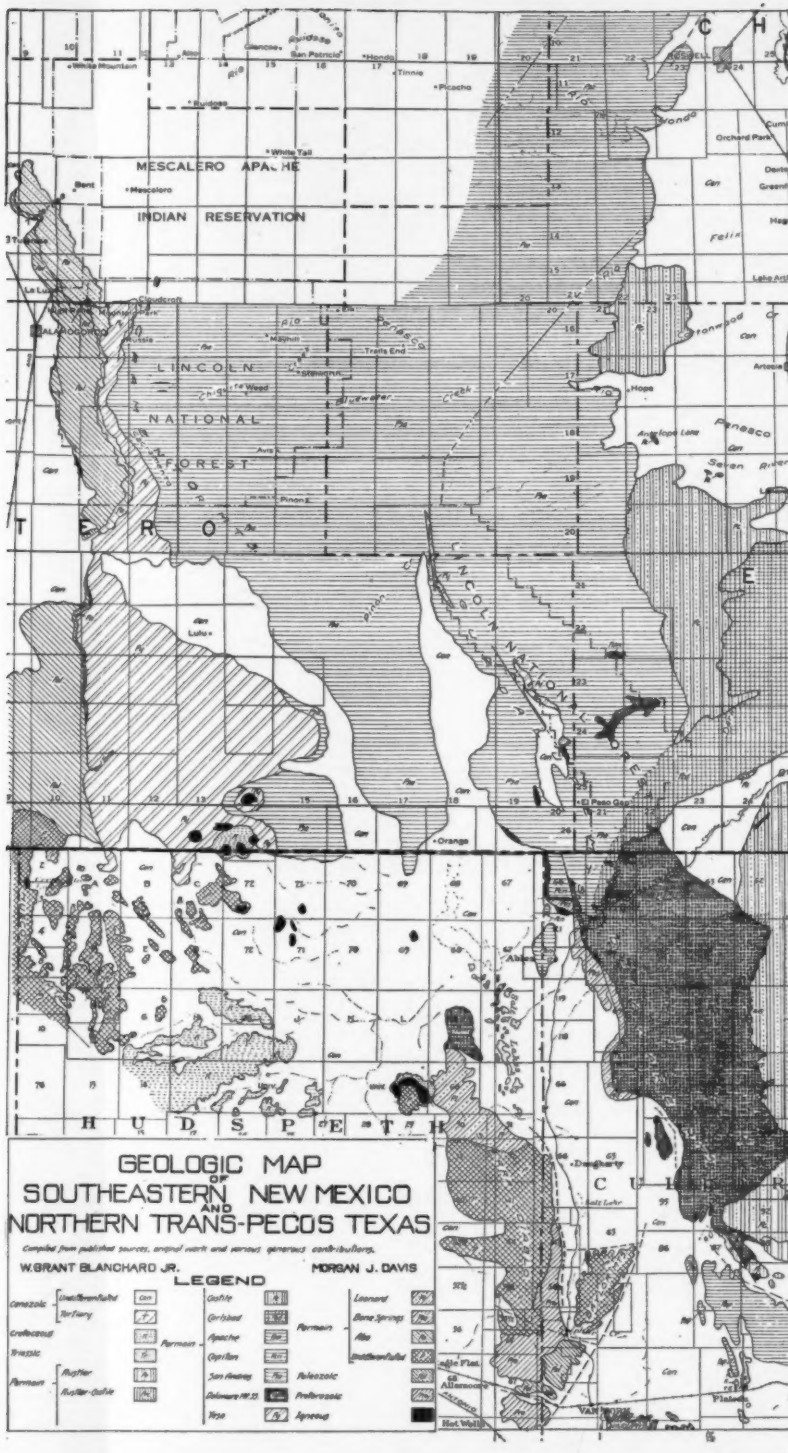
LEWIS SECTION

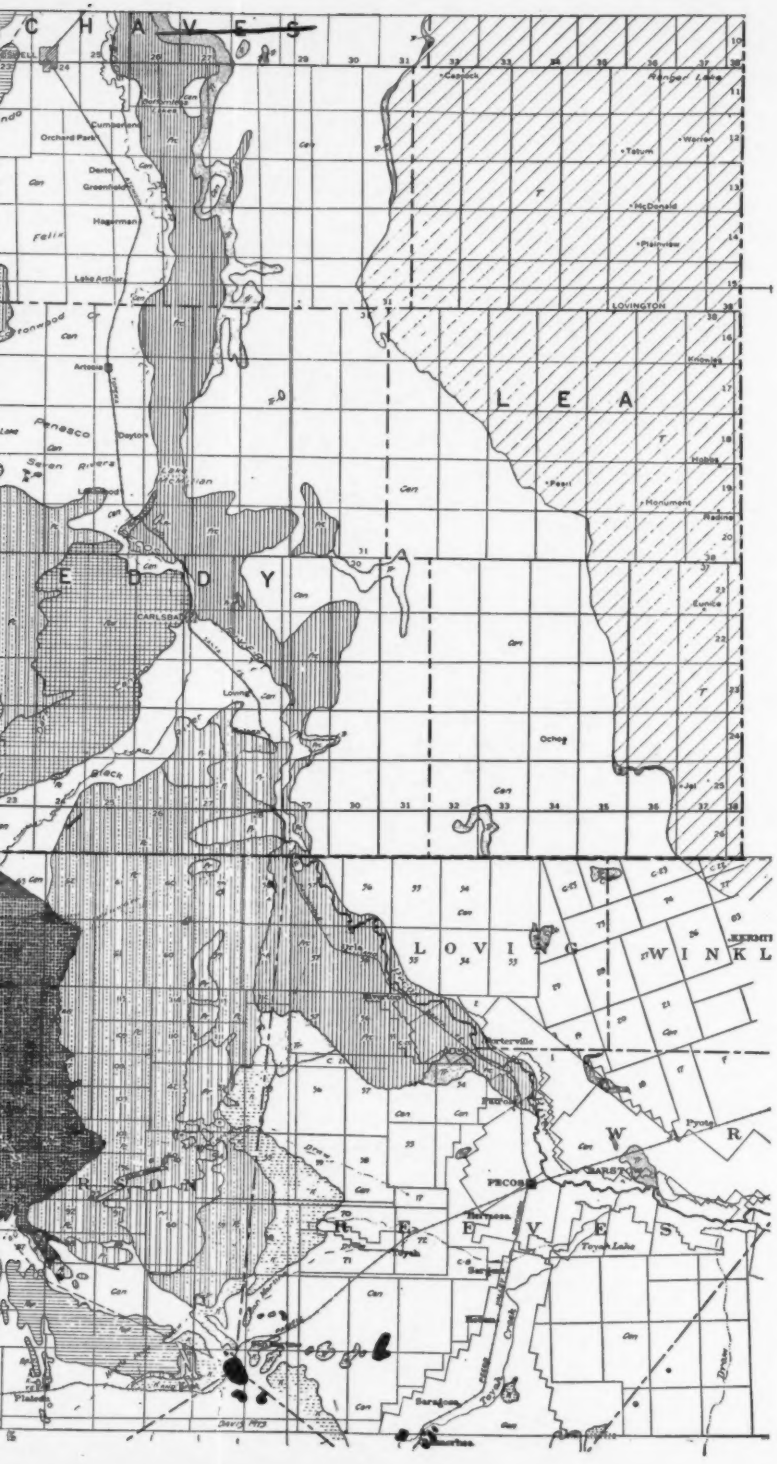
This section was measured in Sec. 18, T. 23 S., R. 20 E., Otero County, New Mexico.

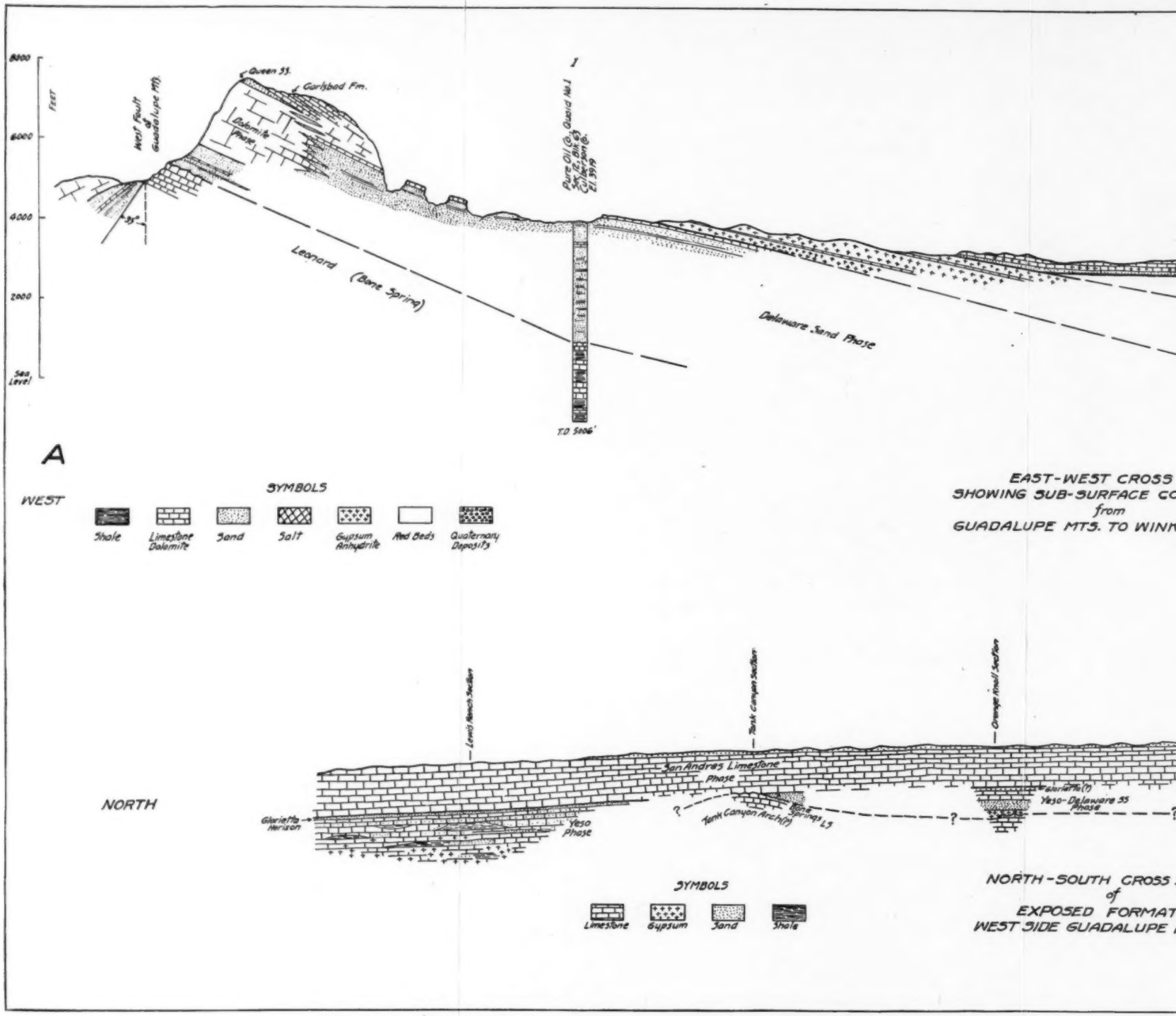
It includes the upper part of the Yeso and most of the San Andres formation. From the base of the main Guadalupe scarp the following section (p. 969) is exposed.

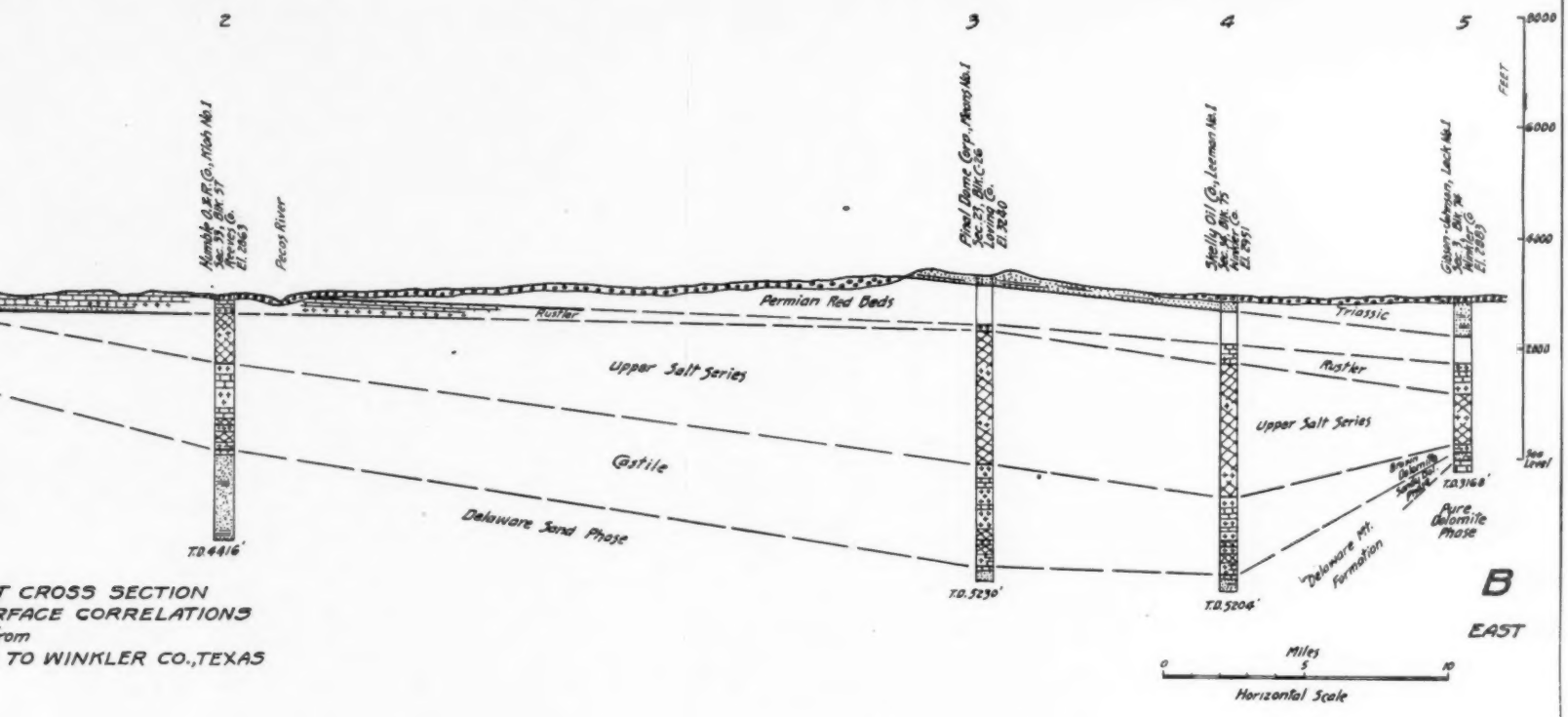
A noteworthy exposure in Sec. 22, T. 26 S., R. 19 E., was measured. This is referred to in Plate 11 as the Orange Knoll section. This section was considered to be composite, partaking of the characteristics of both the Yeso and its contemporary, the Delaware Mountain sandstone.

Summarized, this section contains from base upward: 450 feet of Bone Springs limestone (the top, gray, hackly member); an unconformity; 150 feet of gypsiferous Yeso interbedded with gray and black limestones; 240 feet of typical Delaware Mountain sands; 220 feet of Delaware Mountain sandy limestones, capped by 20 feet of what is possibly Glorieta sandstone. The top limestone, 310 feet thick at this exposure, is lower San Andres.


MESCALERO APACHE
INDIAN RESERVATION
LINCOLN
NATIONAL
FOREST
LINCOLN NATIONAL FOREST
HUDSPETH
CULBERSON
GEOLOGIC MAP
OF
SOUTHEASTERN NEW MEXICO
AND
NORTHERN TRANS-PECOS TEXAS
Compiled from published sources, original work and various generous contributions.
W. GRANT BLANCHARD JR.
MORGAN J. DAVIS
LEGEND
Cenozoic
Undifferentiated
Tertiary
Cretaceous
Triassic
Permian
Rustler
Rustler-Gypsum
Gypsum
Grayburg
Artesia
Queen
Seven Rivers
Yates
San Andres
Delaware Mt. Gp.
Yeso
Leonard
Bone Springs
Abo
Undifferentiated
Paleozoic
Proterozoic
Igneous


CHAVES
LEA
EDDY
LOVING
WINKLER
PECOS
REEVES
Orchard Park
Hagerman
Lake Arthur
Artesia
Dayton
CARLSBAD
Loving
Ochoa
Monument
Hobbs
Eunice
Monahans
Pyote
Barstow
Toyah Lake
Balmorhea
Toyah
Plaines
Davis Mts.


8000
6000
4000
2000
Sea Level
FEET
Queen Ss.
Carlsbad Fm.
Dolomite Phase
West Fault of Guadalupe Mts.
35°
Pure Oil Co. Quasd No. 1
Sec. 12, Blk 63
Culberson Co.
El. 3919
Leonard (Bone Spring)
Delaware Sand Phase
T.D. 5006'
A
WEST
SYMBOLS
Shale
Limestone Dolomite
Sand
Salt
Gypsum Anhydrite
Red Beds
Quaternary Deposits
EAST-WEST CROSS
SHOWING SUB-SURFACE CO
from
GUADALUPE MTS. TO WINK
Lewis Ranch Section
Tank Canyon Section
Orange Knoll Section
San Andres Limestone Phase
Gloriet(a?)
Yeso-Delaware Ss Phase
Red Springs Lg
Tank Canyon Arch(?)
Gloriet(a) Horizon
Yeso Phase
NORTH
SYMBOLS
Limestone
Gypsum
Sand
Shale
NORTH-SOUTH CROSS
of
EXPOSED FORMAT
WEST SIDE GUADALUPE



B

EAST

T CROSS SECTION
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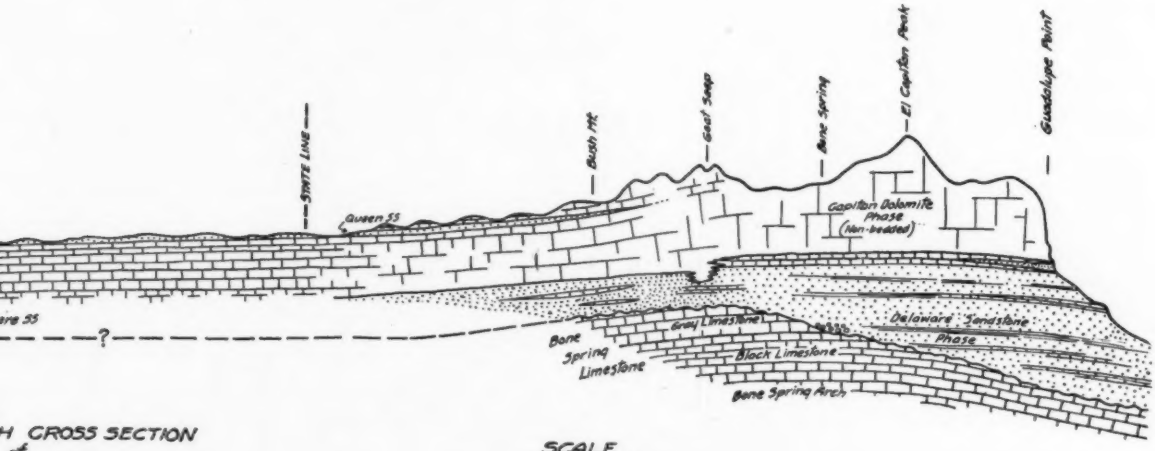
rom
TO WINKLER CO., TEXAS



SOUTH

H CROSS SECTION
of
FORMATIONS
DALUPE MOUNTAINS

SCALE
Horizontal — 2 miles
Vertical — 2000 feet
Thicknesses approximate

SAN ANDRES FORMATION

Thickness in Feet	*Description*
368	Cherty dark gray lime. Honeycombed on weathered surface. Slightly sandy near base. Sandy lime at base. Gray member in middle and upper part pink lime. Top of scarp; probably within 100 feet of Queen sandstone horizon. Last interval above No. 20 measured with aneroid
230	Very fine-grained black lime
20	Uneven gray lime; no bedding planes
87	Gray lime
114	Lime containing some sand. No well defined bedding
10	Sandy horizon full of cigar-shaped forms probably *Fusilina elongata*. Cherty zone
345	Gray lime, dirty brown on weathered surface

YESO FORMATION

20	Gray lime, light and dark; very porous, rough, bedded
70	Greenish, yellowish-brown sandstone
2	Reddish-brown lime
22	Greenish, yellowish-brown fine sandstone
2	Reddish-brown calcitic sandy lime
3	Yellowish-brown fine sandstone
230	Gray lime, no bedding planes; few thin shaly sandy breaks
34	White and gray lime
3	Thin-bedded lime
5	Brownish-yellow, very fine sandstone
59	Dark gray porous lime
3	Dark yellowish-brown sandy shale, laminated
5	Medium-grained soft, yellowish-brown sandstones, irregularly bedded
8	Brownish-drab sandstone
3	Brownish-drab sandy lime
72	Gray lime
5	Thin-bedded light greenish-brown sandstone
4	Dark greenish-brown limy sand, grading upward into sand
36	Gray lime, beds 2 feet thick, interbedded with hard sandy shale
10	Dark gray lime. Angular, wavy beds interbedded with shale
10	Dark greenish-brown shale, slightly sandy
208	Light gray lime, beds 3 feet thick, interbedded with "gyp"(?)
4	Dark gray and brown lime
3	Gray lime
3	Dark gray sandy lime, weathers dark brown
15	Light gray lime; very porous. Beds 1 foot thick
217	Gray lime apparently interbedded with "gyp" although "gyp" is not exposed. Beds 5 feet thick
5	Rough gray lime with calcite nodules
56	"Gyp" with thin limes
4	Gray porous lime, very rough and hard
185	Gray "gyp." Lower 75 feet not exposed very well

ORANGE KNOLL SECTION

SE. cor. Sec. 22, T. 26 S., R. 19 E., Otero County, New Mexico.

Thickness in Feet	*Description*
195	Gray lime
10	Brown, fine-grained sandstone
26	Gray lime
12	Pink sandy lime
57	Gray lime, hard and rough. Base of San Andres limestones
8	Pink limestone
3	Dark brown, fine-grained sandstone
20	Sand, quartz grains, coarser than ordinary. Probably Glorieta
38	Concealed
23	Light brown sandy limestone
15	Pinkish sandy limestone
103	Gray limestone
9	Gray limestone. *Fusilina* near top in chert nodules as in Sitting Bull Canyon section
3	Chert. Local unconformity
23	Brownish-yellow-gray lime, slightly sandy; no bedding planes
15	Pink lime grading downward into massive, hard limy sand, with some soft streaks
228	Yellow and yellowish-brown fine-grained massive sands. Type sands becoming more massive; light orange color locally
64	"Gyp" and thin layers of fine-grained black limestone
7	Gray limestone
101	"Gyp" and black brittle smooth lime, fine-textured; 90 per cent "gyp"
5	Black brittle limestone. Same as at contact at Flexure Canyon; strong bituminous odor. Base of Yeso
	Unconformity
191	Gray hackly limestone. Top Bone Springs limestone
36	Thinner-bedded limestone
222	Gray limestone

It seems in order at this point to mention the possibility of the correlation of the lower Yeso and the Bone Springs limestone (Plate 11), or Leonard formation. The upper Yeso is known to be equivalent to a part of the Delaware Mountain formation which will be discussed later.

The possibility of a correlation of Bone Springs and upper Abo has already been indicated.

Some geologists believe that the change in lithology already noted in the Yeso between Tularosa and the southern end of the Sacramento Mountains also exists in the lower Yeso between Wilkerson's Ranch and Bone Springs Canyon. In each case, if the premise is accepted, a section that is the product of desiccation grades laterally into a marine limestone toward the south. They contend further that some of the limestones seen in the base of the Yeso south of the Grapevine Canyon area and some

of the cuttings from wells which penetrated the Yeso on the east present lithologic characteristics not unlike those of the Bone Springs limestone. There is not sufficient evidence at hand at this time to enable the writers to dispose of this problem. It is hoped that detailed paleontologic work will solve it definitely.

SAN ANDRES DIVISION

The San Andres limestone division of the Chupadera formation is at the top of that series. It is extremely widespread and varies greatly in thickness.

PECOS VALLEY AND LLANO ESTACADO

In the vicinity of Roswell, New Mexico, the maximum thickness of the San Andres is known in subsurface where it attains a thickness of 1,200 feet. It crops out 6 miles west of Roswell. The division is composed of massive, dark gray or dark brown limestones, with a few shale and sandstone partings. The San Andres thins at a uniform rate north of Roswell until in San Miguel County and in wells near Tucumcari, New Mexico, it is only 50-100 feet thick.

Northeast of Roswell toward Clovis, New Mexico, subsurface exploration shows that although the San Andres maintains its thickness of 1,000-1,200 feet, the upper part grades laterally into anhydrite and salt until, in a well 6 miles north of Clovis, only 235 feet of the basal part of the member remains solid limestone.

SACRAMENTO AND GUADALUPE MOUNTAINS

The San Andres member caps the Sacramento Mountains and crops out eastward across the long eastward-dipping cuesta from the crest of the Sacramento to the previously mentioned point 6 miles west of Roswell. This limestone lies on the surface throughout the southeastern part of the Sacramentos to the area beyond Orange, New Mexico, where it becomes involved in the north end of the faults paralleling the Sierra Diablo Plateau and the Guadalupe Mountains. The San Andres and its equivalent are the massive limestones forming the upper and major part of the "Main" escarpment along the west side of the Guadalupe Mountains approximately to the state line. South of the state line a distinct faunal and lithologic change has been noted by Darton[1] and will be discussed later. A thickness of more than 1,000 feet has been measured in the Guadalupe Mountains.

[1] *Bull. Geol. Soc. Amer.*, Vol. 37, No. 3, p. 419.

Remnants of the southern extension of the San Andres cap the outliers adjacent to the Cornudas Mountains, a group of intrusives referred to previously.

The San Andres limestones are fossiliferous, but satisfactory specimens are difficult to obtain, as the stone fractures across the fossil. The most exceptional specimens collected were large nautiloids, some of which were 12 inches in diameter. These cephalopods were discovered 65 miles west of Artesia, after a blast in a side hill cut on the new Artesia to Cloudcroft highway. The forms were not noticeable on a weathered surface.

QUEEN SAND ZONE

A sandy limestone and sand zone notable near the old postoffice at Queen, Eddy County, New Mexico, is often referred to by New Mexico geologists as the "Queen sandstone."

Queen is located on a plateau or mesa at the north end of Dog Canyon, in the Guadalupe Mountains. The mesa is commonly referred to as Queen mesa

The "Queen sandstone" is composed, primarily, of reddish-brown and gray sandstones interbedded with hard gray limestones that are locally sandy. These sandstone lenses lie in the uppermost part of the San Andres limestone and the Queen sand zone is considered the top of that formation. Because there are several of these lenses within 200 feet or more of section, the term *zone* is applicable.

These sandstones have been traced from their type locality southwest to El Paso Gap, through Dog Canyon to Bush Mountain (a high mass in the Guadalupes) and southward to a point approximately 5 miles south of the state line. This locality is approximately 1 mile northeast of El Capitan (elevation 9,020 feet), the highest peak in the Guadalupes. An important fact is that the upper lenses of the Queen zone are stratigraphically within 300 feet of the top beds of El Capitan. Remnants of the Queen zone sandstones were found at the head of Pine Canyon on the first ridge of hills east of El Capitan. Throughout the areal extent of the Queen sandstone zone, it maintains its distinct lithologic characteristics.

The Queen outcrop is crossed on the steep road several miles east of Queen Postoffice. At this point it dips steeply north and northeast, taking its position at the base of the gypsum beds in the Carlsbad member. Beede[1] reports fossils in the Queen zone resembling the fauna of the Whitehorse sandstone.

[1]Personal communication.

DELAWARE MOUNTAIN FORMATION

Very little need be said concerning the lithology and thickness of the Delaware Mountain sandstones. The formation has been described ably by Beede, Richardson, and others. Its fauna has been indexed well by Girty[1] and his associates.

The sandstones are extremely fine-grained when considered as a whole. They are generally light yellow or light gray in color. A few dense, dark limestones are intercalated with them. So fine is the texture of the sandstones that in many places they appear to be shales when viewed from a short distance.

GUADALUPE MOUNTAINS

Many examples of thickening and thinning of individual beds may be seen in the middle part of the formation near Guadalupe Canyon. The formation is capped by a dark shaly limestone that will be designated in this paper as the Frijole limestone. This member is extremely persistent and is recognizable in well cuttings as far east as western Winkler County. Below the Frijole limestone, deep in the sandstone section, other limestone members are present that lithologically are practically indistinguishable from the Frijole. At the base of the sandstone is an angular unconformity already mentioned. This unconformity is well displayed in Bone Springs Canyon, where it is marked by a conglomerate more than 100 feet thick (Fig. 10).

At Guadalupe Point, Richardson's[2] measured section of the Delaware sand series, including the top dark limestone, was 2,025 feet thick. The total thickness of a recently measured section at the same place is nearly 2,300 feet.

DELAWARE AND APACHE MOUNTAINS

In Blk. 76, Culberson County, Texas, Beede[3] measured a maximum section of 3,500 feet of the Delaware sand section, including the upper dark limestone member (Frijole). The proportion of limestone in the upper part of the section increases southward from this locality. In True Canyon, north and slightly east of Seven Heart Gap[4] in the Apache Mountains, the exposed Delaware Mountain formation consists mainly of

[1] *U. S. Geol. Survey Prof. Paper 58.*

[2] *U. S. Geol. Survey Prof. Paper 58*, p. 10.

[3] *Univ. of Texas Bull. 2346* (1923), Plate I.

[4] Locality in southeastern part Van Horn Quadrangle, *U. S. Geol. Survey Folio 194.*

limestone, although the characteristic bench type of topography so noticeable in the Delaware Mountains is preserved. The section here exceeds 400 feet.

For 5 miles along the northeast side of the Apache Mountains, separated from them by a bolson-filled valley traversed by faults, the upper part of the Delaware Mountain sand section skirts these mountains.

DOLOMITIC LIMESTONE PHASE OF THE DELAWARE MOUNTAIN FORMATION

From Guadalupe Point in Culberson County, Texas, to the town of Carlsbad, New Mexico, a prominent escarpment of dolomite and dolomitic limestone occurs. This escarpment is composed on the whole of dolomitic limestone that is remarkable because of the total lack of bedding plane in many places and the vertical jointing displayed on weathering. The color of the limestone on fracture is white or cream. Near the rim of the escarpment, the great mass develops pseudo-bedding planes which appear to plunge toward the southeast at a tremendous rate. A bolson-filled valley flanks this escarpment all the way from Carlsbad to a short distance north of the state line. Deep canyons are cut into the scarp at intervals by drainage channels.

The escarpment rises from an elevation of 3,200 feet at Carlsbad to 8,500 feet at Guadalupe Point. The relief at Carlsbad is negligible, but at the Point it exceeds 4,000 feet.

When one traverses any one of the deep canyons from the first canyon north of the state line to Guadalupe Point (five canyons are noted), he is confronted by a remarkable transition. The upper part of the characteristic Delaware sand section capped by the dark *Frijole* limestone abruptly loses its identity and is replaced by the massive light-colored, non-bedded dolomite. The best exposures are in McKittrick Canyon, first canyon south of the state line, and in Guadalupe Canyon, the first canyon east of Guadalupe Point. In McKittrick Canyon approximately 1,000 feet of upper Delaware sand is replaced in the section by the massive dolomite within a distance of ¼ mile. In Guadalupe Canyon as much, or more, section is involved (Fig. 2). Thus, it is seen that a zone of lithologic change parallels the northeast-trending escarpment, but is set back a short distance from the face.

The massive dolomitic limestone previously described has been referred to by all writers on this area as the Capitan limestone. Approximately 1,200 feet of it overlies the Delaware sand series at Guadalupe Point, and beneath El Capitan Peak on the west face of the mountains 1,800 feet of this material is exposed in one sheer cliff.

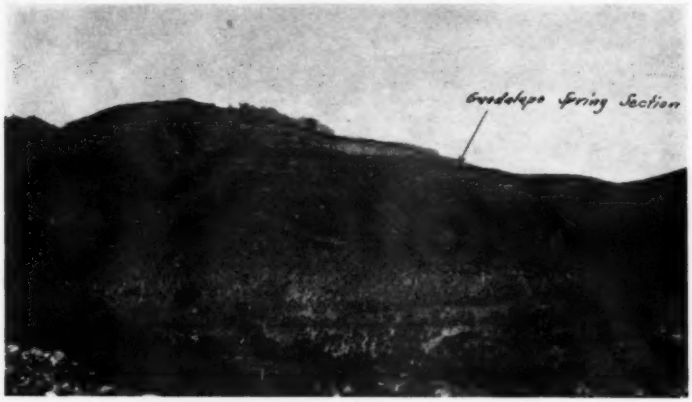


FIG. 2.—Delaware-Capitan transition, Guadalupe Spring, Culberson County, Texas. *D* = Delaware sand; *C* = Capitan lime.

To explain the sudden change in sedimentation, that is, from dolomite to sand, it is necessary to refer again to the Bone Springs arch, already described. From wells drilled much farther east, the axis of this arch is known to trend northeast, that is, to parallel the Carlsbad-Guadalupe Point escarpment. Along this positive line, which has already been shown to have acted as a barrier between desiccating seas on the north and normal seas on the south, reef-building agencies deposited the great mass of Capitan limestone. The sudden change is due to the sands of the Delaware Mountain formation washing up against the reef barrier.

The steep pseudo-dips already mentioned were viewed from the air and were found to extend along practically the entire length of the escarpment from Carlsbad to the Point. They appear to be "flows" of lime ooze and reef débris that developed bedding planes when "poured" over the outer margin of the reef (Figs. 3 and 4). This condition was referred to in a quotation from Rudolph Ruedemann given by P. B. King and R. E. King[1] in their Glass Mountain discussion.

It has been the junior writer's privilege to spend some time in the Guadalupe Mountains with G. M. Lees, senior geologist of the Anglo-Persian Oil Company. Lees, from a background of much experience with reef dolomites of the Tyrolean Alps and other dolomites of the same

[1] *Univ. of Texas Bull. 2801.*

FIG. 3.—Pseudo-dips and bedding planes in Capitan formation.

origin in Persia and Arabia, gave much valuable assistance in finding the criteria of coral reefs in the Capitan limestone.

In the Apache Mountains a very similar condition is found. As already noted, characteristic Delaware Mountain formation is found in the escarpments across Seven Heart Gap from the main body of the Apache Mountains. West of Seven Heart Gap, the massive, non-bedded Apache limestone lies in apparent juxtaposition with the typical Delaware formation on the east side of the Gap. It is true that a system of faulting extends through Seven Heart Gap, separating the two exposures, but subsequent investigation has revealed that the displacement is much less than that found along the same fault system on the southeast.

The Apache limestone is a white to light gray non-dolomitic limestone. The lack of bedding planes in many places has been noted. Richardson[1] described the member, but did not measure the thickness, which can not be less than 700 feet. Pisolitic zones strongly resembling those found in the upper Capitan were seen. About 2 miles west of Seven Heart Gap there is an exposure of Delaware sand at the base of the escarpment of Apache limestone. In many places on the west side of the Apache Mountains, near the top of the limestone, thin-bedded platy limestones, some of which are sandy, were noticed. These were strongly suggestive of the limestones and shales in the upper Delaware Mountain

[1] *U. S. Geol. Survey Folio 194.*

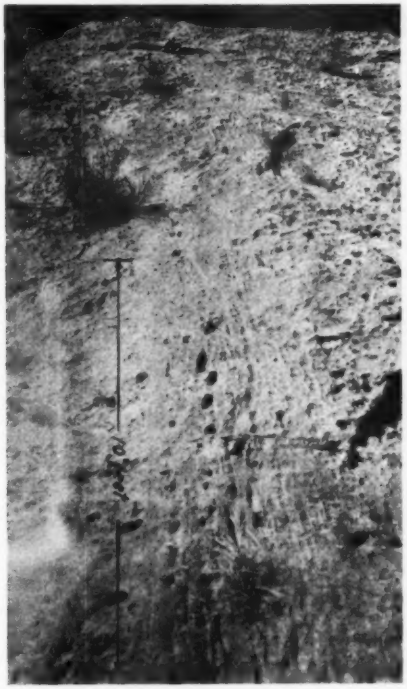


FIG. 4.—Characteristic surface of material "poured over" outer slopes of reefs. Figure 4 is the lower central part of Figure 3.

formation at its type locality. This close association of characteristic Delaware material with the Apache limestone, coupled with the relative positions of the exposures across Seven Heart Gap, led to the belief that the Apache limestone was an upper Delaware Mountain equivalent. Fossil evidence substantiated this conclusion. In the autumn of 1928, Vaughn C. Maley made fossil collections along the Apache Mountains which were subsequently identified by Girty. The following excerpt from the letter of Julian D. Sears, of the U. S. Geological Survey, relative to this collection sums up Girty's findings:

> Concerning the relative ages of the 5 collections examined, the paleontologic evidence is quite clear. In the light of our present knowledge, lots 1 and 4 carry the fauna of the Capitan limestone while lots 2, 3 and 5 carry the fauna of the Delaware Mountain formation. It would be well to bear in mind, however, that our present knowledge of this region is exceptionally incomplete

and that this region, we have every reason to believe, was one of shifting conditions and doubtless shifting faunas to correspond.

Groups 1 and 4 were collected near Seven Heart Gap and from a point rather low in the Apache section. Groups 2 and 3 were collected south of the Gap from the upper part of the Apache section. A list of the fossils collected and identified follows:

GROUP 1

Collected in the Apache Mountains 1½ miles northeast of B. M. 3899

Squamularia guadalupensis
Dielasma spatulatum?
Spiriferina evax
Pugnax swallowiana
Camarophoria? sp.
Rhynchonella indentata
Rhynchonella or *Camarophoria*—ind.
Spirifer mexicanus
Composita emarginata
Dielasma sentulatum?
Ambocoelia planiconvexa, var. *guadalupensis*
Rhynchonella longeeva
Pugnax shumardiana?
Composita emarginata, var. *affinis*
Orthoceras sp.
Dielasma cordatum
Plagioglypta canna?
Heterelasma shumardianum
Orthotetes guadalupensis
Camarophoria venusta
Martinia rhomboidalis
Pugnax elegans?
Notothyris schuchertensis
Naticopsis? sp.
Spiriferina billingsi
Hustedia meekana

GROUP 2

Collected in the Apache Mountains 1½ miles southeast of Jones ranch house

Spirifer sp.
Meekella skenoides?
Coral ind.
Meekella difficilis?
Domopora terminalis
Sponge ind.
Hustedia meekana
Fusilina elongata
Sponge ind.

GROUP 3

Collected in the Apache Mountains ¾ mile west of Jones ranch house

Schwagerina? sp.
Productus subhorrides, var. *rugatulus?*
Sphaerodoma? sp.
Camarophoria? sp.
Orthoceras guadalupensis
Hustedia meekana
Chonetes permianus
Pleurotomaria n. sp.
Spirifer sp.
Ambocoelia arcuata

GROUP 4

Collected in the Apache Mountains 1 mile south of Seven Heart Gap

Martinia rhomboidalis
Pugnax swallowiana
Fusilina elongata
Gastrioceras roadense?
Cyclotrypa barberi?
Goniatite ind.
Waagenoceras sp.
Productus n. sp.
Pugnax bisulcata, var. *gratiosa*

GROUP 5

Collected in the Delaware Mountains in True Canyon 5 miles northeast of Seven Heart Gap

Waagenoceras cumminsi var. *guadalupense*
Composita emarginata var. *affinis*
Spiriferina laxa?
Productus popei?
Waagenoceras? sp. *a*
Waagenoceras? sp. *b*
Gastrioceras altudense?
Gastrioceras n. sp.
Cryptacanthia n. sp.
Pugnax shumardiana?
Hustedia meekana
Meekella attenuata?
Goniatite type *a*
Spiriferina billingsi?
Stachioceras bowmani?
Gastrioceras serratum?
Pugnax bisulcata var.

Thus the paleontologic evidence not only bears out the field conclusions regarding the correlation of the Apache and Delaware Mountain, but also indicates the probability of its equivalence to some part of the Capitan.

The junior writer also accompanied G. M. Lees on an excursion through the Apache Mountains. Here also evidences of the reef origin of the Apache limestone were noticed and discussed.

It should be noticed at this point that the type locality of the Capitan and Delaware Mountain formation has been proved, by recent work, to be an unfortunate selection. This is due to the fact that the greater part of the massive Capitan limestone at Guadalupe Point has been found to be, in reality, the equivalent of the Delaware Mountain formation.

As has been stated, Girty described a dark limestone at the top of the Delaware sand series at the Point which was overlain by the massive Capitan. This dark limestone, until recently, has been universally accepted as the Frijole limestone which caps the Delaware Mountain formation at McKittrick Canyon and southward. This is not the fact. Most of the massive limestone above the sand at Guadalupe Point belongs below the Frijole limestone in the section.

For one who is not familiar with the terrane between Guadalupe Point and McKittrick Canyon, it is probably difficult to understand how Girty's dark limestone at the Point could be mistaken for the Frijole limestone northeast. Because there are few bedding planes in the massive dolomitic limestone, it is extremely difficult to follow beds from one locality to the other. The pseudo-dips already mentioned further complicate the situation. Lithologically, the Frijole and dark limestone are very similar. The Frijole limestone, however, was traced to Guadalupe Canyon, of which Guadalupe Point forms the west side, and at the place where it lost its identity through transition into the massive

dolomite it was above approximately 1,000 feet of the dolomite of Capitan facies. At its point of disappearance, projection of the last dependable dips seen on the Frijole would have placed it near the top of El Capitan Peak.

The major part of the dolomitic limestone (that below the Queen sandstones at the head of Pine Canyon) in the sheer cliff above the dark lime at Guadalupe Point is merely the limestone, or reef phase of the Delaware Mountain formation. It so happens that erosion has placed the promontory of Guadalupe Point a short distance northwest of the northeast-southwest-trending line of change already described. The transition has brought the dolomite hundreds of feet lower in the section than the Frijole limestone. Coincidence has placed a dark limestone at the sand-dolomite contact at this place which has contributed greatly to the former misconception. Darton[1] gives a clue to this situation when he states that according to Girty's determination, species collected from the dark limestone (Frijole limestone) at the mouth of Big Canyon occur high in the Capitan limestone at Guadalupe Point.

It may help the reader who is unfamiliar with this region of "shifting conditions" of sedimentation if he will consider the following facts. Beede[2] measured 3,500 feet of Delaware Mountain formation (exclusive of the Bone Springs limestone) in the Delaware Mountains (Blk. 46, Culberson County). The Pure Oil Company's No. 1 Quaid (Sec. 12, Blk. 63, Culberson County) was commenced 425 feet below the top of the formation and was drilled approximately 3,000 feet before penetrating the underlying Bone Springs limestone. Thus these two sections each show more than 3,400 feet of the formation, although at Guadalupe Point the thickest section of Delaware Mountain sand is only 2,300 feet. The other 1,100 feet is represented by the Capitan dolomite phase. The section at Guadalupe Point is far enough south to have escaped the thinning influence of the Bone Springs arch.

Above the Queen beds at the head of Pine Canyon is higher dolomite that probably includes only the top beds on El Capitan Peak. These beds are locally identical with the Capitan phase of the Delaware although farther east they develop slightly different characteristics and assume relationships that entitle them to be designated as a separate formation. They will be discussed later as the Carlsbad[3] formation. In

[1] *Bull. Geol. Soc. Amer.*, Vol. 37 (1926), p. 424.

[2] *Univ. of Texas Bull. 2346* (1923), Plate I.

[3] *U. S. Geol. Survey Water Supply Paper 580-A.*

earlier writings these beds were relegated to the Capitan formation in the vicinity of Guadalupe Point.

In view of the foregoing discussion, it can be seen that the lower and major part of the Capitan is in reality the limestone of the upper Delaware Mountain formation.

It has been stated that the Queen sand zone has been found almost as high stratigraphically as the beds at the top of El Capitan Peak. It appears that the Queen zone is very close to the stratigraphic position of the Frijole limestone. The beds above the Queen zone have been found to be a part of the Carlsbad formation farther east. Actually, therefore, the Capitan limestone, as originally described, is a part of two formations, the Delaware Mountain and the Carlsbad, and the term could be dropped from the literature unless it is used with a clear understanding of the various relationships.

When the previously mentioned dolomitic limestone mass is traced along the Guadalupe escarpment northward from El Capitan Peak, the upper beds (Carlsbad equivalent) are found to have been removed by erosion before the state line is reached. At approximately the state line, the whole non-bedded mass grades laterally into the bedded San Andres limestone facies which is capped by the Queen sand zone. As the San Andres division of the Chupadera, therefore, these beds extend far toward the north, as has been described. It has been stated already that the fauna changes correspondingly at approximately this point of change in lithology.

Near the state line, after the transition into the San Andres facies is completed, these beds overlie characteristic Delaware Mountain sands. In Otero County, New Mexico, from Sec. 34, T. 23 S., R. 20 E., and for 30 miles northwest, they overlie unmistakable Yeso strata. Thus, the upper and middle Yeso occupies the same stratigraphic position as the middle and lower part of the Delaware Mountain formation, and is considered to be its equivalent. The Orange Knoll section offers a clue to the relationship.

An interesting lithologic variation within the San Andres division was observed in Last Chance and Sitting Bull canyons in southwestern Eddy County, New Mexico. In this locality, a large part of the San Andres section has reverted to the lithology of the Delaware Mountain sand series. Darton and Reeside[1] collected fossils in this locality and found that they too had assumed a Delaware Mountain facies. The curious fact was noted that although a preponderance of sands occurred

[1] *Bull. Geol. Soc. Amer.*, Vol. 37 (1926), pp. 424-27.

in the section, the characteristic San Andres type of topography was largely preserved.

SITTING BULL CANYON SECTION

This section was measured in Sec. 34, T. 23 S., R. 22 E. The Sitting Bull Canyon section comprises the total thickness of the San Andres limestone. The section is as follows:

SAN ANDRES FORMATION

Thickness in Feet	*Description*
25	Gray lime
3	Sandy lime
27	Gray lime
2	Gray lime
10	Buff sandstone
2	Lime
45	Buff and gray lime
3	Smooth buff sandstone
10	Darker gray lime
5	Gray and brownish-gray lime
15	Light brown fine-grained sandstone
17	Gray lime
9	Light buff fine-grained sandstone
3	Gray lime
4	Fine light pinkish gray sandstone
22	Gray lime
9	Smooth fine-grained sandstone, light pinkish cast, slightly limy
3	Sandy brownish-gray lime
19	Brownish-gray lime
23	Buff lime
4	Light buff sandstone
12	Four feet light buff sandstone, weathers dark brown, 8 feet gray lime
13	Buff sandstone, limy at base
24	Sandy lime, gray
70	Some sand and sandy lime, grading upward into lime. Many cigar-shaped calcite forms and cherty nodules containing sand forms, probably *Fusilina elongata*
81	Sandy lime, probably 60 per cent lime, more limy near top
130	Harder yellowish-brown sandstone, limy; homogeneous and even-textured
19	Yellowish-brown sandstone
3	Bright yellow, coarser sandstone
28	Yellowish-brown medium-grained pure sand; soft; resembling Glorieta
3	Massive brown medium-grained soft sandstone
10	Chocolate-brown lime, calcite nodules, 2 feet sand at base
6	Yellow and white coarse sand, limy at base
56	Buff lime
7	Buff lime, cherty at top with one 6-inch sandy streak
40	Very dark gray, nodular lime; no bedding planes, cherty bituminous odor

CARLSBAD FORMATION

Masses and beds of limestone lying above the Queen sand zone have already been noted. Northeast, toward the town of Carlsbad, New Mexico, as the lower beds begin to plunge under, more beds have been left by erosion on the top of the section. This section of dolomitic limestone above the Queen sands constitutes the Carlsbad formation.[1] It crops out throughout an area 10-12 miles wide from approximately the southwest corner of Eddy County, New Mexico, to the south end of Lake McMillan in the same county (Plate 10).

As a whole, the formation, in its limestone phase, is made up of light gray to light brown thin-bedded limestones and dolomitic limestones. A few sand lenses have been noticed.

The limestone phase of the formation becomes much thinner northward and on the east shore of Lake McMillan it pinches to less than 50 feet and grades laterally into red beds and gypsum. In the southern part of the Guadalupe Mountains and along the escarpment from there to Carlsbad, New Mexico, the formation is a solid section of dolomitic limestone, but north, east, and west of that town, as the limestone phase thins a thick gypsum and red-bed wedge comes in beneath the limestone and over the Queen zone to take the place of the thinning upper part. After the limestone lenses out entirely, the Carlsbad formation equivalent, made up of thin dolomites, anhydrite, gypsum, and red beds, continues far toward the north and east. Although basinward some younger gypsum comes in above these beds, the greater part of the dolomite, anhydrite, and red-bed series above the San Andres limestone division is Carlsbad equivalent. These beds are commonly referred to as Castile.

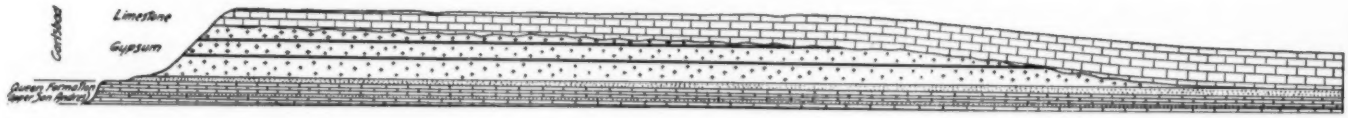
In Rocky Arroyo (T. 21 S., R. 24 E.) and Dark Canyon (T. 23 S., R. 24 E.), Eddy County, drainage has exposed interesting sections showing the start and considerable development of the gypsum wedge previously mentioned (Fig. 5). The condition has been interpreted generally as a gradation or transition from dolomite into gypsum, but there is good reason to believe that the dolomite overlying the gypsum may represent a transgressional overlap, in which case the gypsum would be slightly older than the dolomite. At no point was positive evidence of interdigitation between the gypsum and the dolomite found by the writers.

The Queen sand zone lies at the base of the gypsum wedge. At the base of the dolomite above the wedge is a thin, impure, red to purplish dolomite. The material between these limits consists of red gypsiferous sands and shales and beds of white and red gypsum. Within less than 2

[1] *U. S. Geol. Survey Water Supply Paper 580-A.*

CROSS SECTION OF LOWER CARLSBAD GYP & LIME SERIES

IN ROCKY ARROYO, SEC5, 28 & 29 T. 21 S., 24 E.
Eddy County, New Mexico



WEST

EAST

SYMBOLS

FIG. 5

miles from the point of initial "overlap," it has attained a thickness of more than 500 feet. After the two bodies of dolomite converge toward the east, they form an almost homogenous section. Even the dividing lenses of sand grow indistinct.

Many discussions have been held regarding these almost unique exposures. The explanation here offered should be regarded, of course, only in the light of a hypothesis.

Following the deposition of the San Andres limestone division of the Chupadera formation, it is believed that reef building on the southeast flank of the arch continued throughout Carlsbad time. As the reef grew higher, the waters north of the Bone Springs arch were restricted by it. This basin was closed on the south, but was open on the north. When desiccation began, this basin, which is outlined on the southeast by the present Carlsbad outcrop, filled up with anhydrite and red beds which continued far toward the north and northeast. At the close of this period, fresher waters, their source probably farther south, came over the barrier reef and decreased the concentration a short distance north and west. They brought with them enough calcium carbonate, the amount probably increased by the proximity of the reef, to spread a mantle of dolomite beyond the solid reef and over the gypsum beds. This mantle thinned rapidly north and west, entirely losing its identity in the vicinity of what is now Lake McMillan and at points slightly west of the present outcrops in Rocky Arroyo and Dark Canyon. This was either due to the fact that the increments of fresh sea water from the south were not sufficient to dilute the saline waters of this restricted sea to a greater distance; or that these points were so far from the reef that dolomitic material in the form of lime ooze or débris could not be mechanically transported farther.

CASTILE GYPSUM

It has already been a subject of discussion that the Carlsbad formation, grading laterally into the anhydrite, dolomite, and red-bed series, lies above the limestone or dolomite phase of the Delaware Mountain formation. The Carlsbad and younger beds of gypsum, red-beds, and salt, make up the series known as the Castile gypsum or formation. Richardson, Darton, Hoots,[1] and others have described this formation. Lon D. Cartwright, Jr. has also described the series in full.[2]

[1] *U. S. Geol. Survey Folio 194*, p. 6.
Bull. Amer. Assoc. Petrol. Geol., Vol. 10, No. 9 (September, 1926), p. 847.
U. S. Geol. Survey Bull. 780-B, p. 65.

[2] "The Castile Formation Re-Defined." Unpublished paper.

DELAWARE AND APACHE MOUNTAINS

Where not removed by erosion, the Castile formation lies conformably on the Delaware Mountain sand series. The contact trends almost north and south through central Culberson County, Texas.

In the Empire Gas and Fuel Company's Rose No. 1 in Sec. 31, T. 24 S., R. 36 E., Eddy County, New Mexico, approximately 1,600 feet of the formation was drilled. No salt was found here until the well reached a depth of 1,400 feet.

The lower part of the Castile formation in this well (from a depth of 900 feet to the top of the Frijole limestone, an interval of 1,250 feet) carries a considerable amount of limestone along with the anhydrite and salt. This part of the section is the equivalent of the Carlsbad formation.

The upper part of the section is composed of an earthy, non-crystalline type of gypsum. This part of the column is correlated with that part of the gypsum-red bed strata that has been mentioned as being younger than the Carlsbad equivalents on the north. Farther east, a thick salt series wedges into this part of the section.

In the Apache Mountains, Richardson[1] described 275 feet of Castile formation on the northeast side of Seven Heart Gap. Here it overlies characteristic Delaware Mountain formation. Toward the southeast end of these mountains, the Castile is found lying in apparent conformity on the Apache limestone phase of the Delaware Mountain formation. On both sides of Seven Heart Gap, gypsum has almost disappeared from the Castile, and the formation is practically pure limestone. Noticeable in these beds are zones of banded aragonite that, when hammered, emits a fetid odor.

RUSTLER FORMATION

On the outcrop, the Rustler formation consists of white to brown dolomite beds, streaks of gypsum, reddish sandstones, and red shales. Hoots[2] measured 75 feet of characteristic material at Red Bluff, Eddy County, New Mexico (T. 25 S., R. 28 E.).

In the Apache Mountains, Richardson[3] describes 200 feet of Rustler. The formation is composed almost entirely of gray to brown dolomite that weathers in a peculiar "tortoise-shell" type of surface. A red,

[1] *U. S. Geol. Survey Folio 194*, p. 3.

[2] *U. S. Geol. Survey Bull. 780-B*, p. 73.

[3] *U. S. Geol. Survey Folio 194*, p. 3.

pebbly sandstone, 20-30 feet in thickness, with local developments of conglomerate, is found at the base.

When the Rustler is traced eastward into the salt basin by subsurface data, it is found capping the "upper" salt series that lies above the Carlsbad equivalent of the Castile formation. In the middle of the basin, the Rustler, represented by dolomite stringers, anhydrite, red beds, and salt lenses, attains in many places a thickness of 200 feet (Fig. 6). The Rustler time equivalent is probably present in the upper part of the gypsum, anhydrite, and red beds above the San Andres.

Above the Rustler, lie red beds of Permian age, variable in thickness, and which are often referred to as Pecos Valley Red-beds. The red shales and sandstones that compose these measures, where not removed by erosion, are spread over the entire Permian basin.

Beede[1] has suggested that these beds might be correlated with that part of the Oklahoma section embracing Cloud Chief gypsum and the lower part of the Quartermaster formation. Hoots[2] has suggested that the Pecos Valley Red-beds are possibly the upper part of the Rustler formation.

Red beds of Triassic age overlie unconformably the Pecos Valley Red-beds. These beds are assigned to the Dockum group of northern New Mexico by N. H. Darton.[3] They consist of dark red shales and coarse-grained sandstones which are locally conglomeratic. Throughout the Llano Estacado the Dockum group is in turn overlain by the Mescalero sands and caliche of Cenozoic age.

DISCUSSION OF ANOMALIES IN THE SUBSURFACE

A reference to Figure 7 calls attention to the fact that three distinct types of sections have been encountered in test drilling in southeastern New Mexico and northern trans-Pecos Texas.

The following wells are illustrative of the three sections:

NEW MEXICO (ROSWELL) SECTION

Buffalo-Roswell Company's Sierra No. 1, Sec. 25, T. 11 S., R. 27 E., Chaves County, New Mexico.
Marland Oil Company's Bell Ranch No. 1, Sec. 3, T. 13 N., R. 29 E., San Miguel County, New Mexico.
Ohio Oil Company's Samuel Wells No. 1, Sec. 24, T. 7 N., R. 29 E., Quay County, New Mexico.

[1] *Amer. Jour. Sci.*, 4th Ser., Vol. 30 (1910), p. 136.

[2] *U. S. Geol. Survey Bull. 780-B*, p. 75.

[3] N. H. Darton, *U. S. Geol. Survey Bull. 726*.

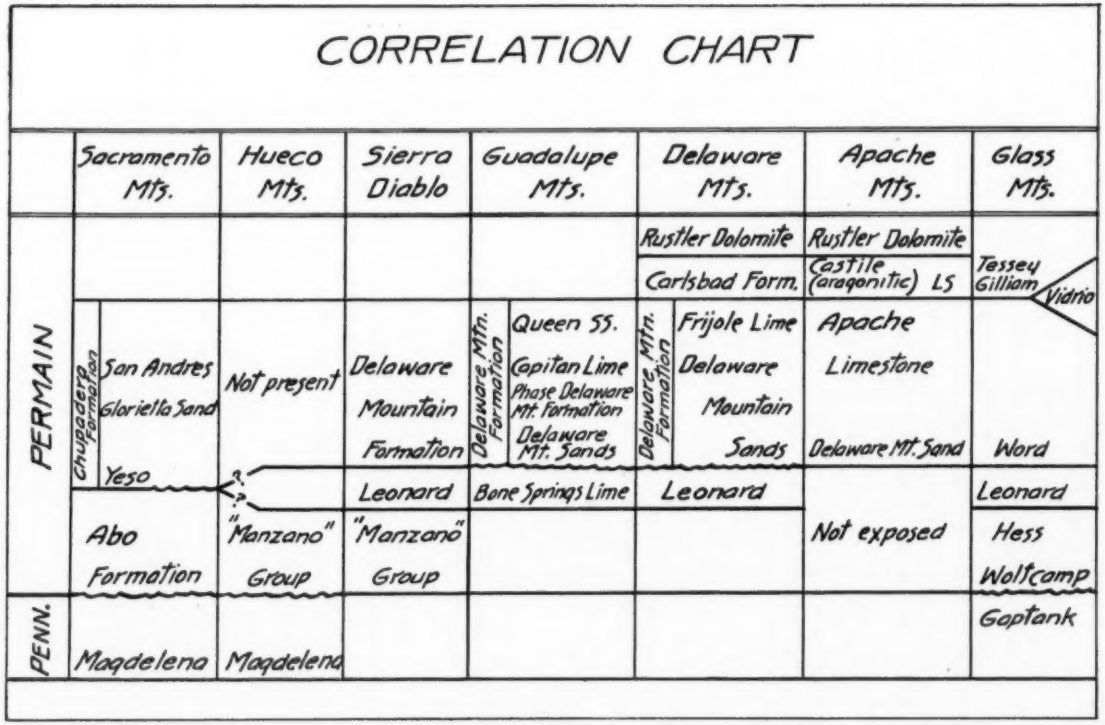

CORRELATION CHART
Sacramento Mts.
Hueco Mts.
Sierra Diablo
Guadalupe Mts.
Delaware Mts.
Apache Mts.
Glass Mts.
PERMAIN
PENN.
Rustler Dolomite
Carlsbad Form.
Rustler Dolomite
Castile (aragonitic) LS
Tessey
Gilliam
Vidrio
Chupadera Formation
San Andres
Gloriella Sand
Yeso
Abo Formation
Not present
"Manzano" Group
Delaware Mountain Formation
Leonard
"Manzano" Group
Delaware Mtn. Formation
Queen Ss.
Capitan Lime
Phase Delaware Mt. Formation
Delaware Mt. Sands
Bone Springs Lime
Delaware Mtn. Formation
Frijole Lime
Delaware Mountain Sands
Leonard
Apache Limestone
Delaware Mt. Sand
Not exposed
Word
Leonard
Hess
Wolfcamp
Gaptank
Magdelena
Magdelena

FIG. 6

TYPE SUB-SURFACE SECTIONS

AGE	FORMATIONS	NEW MEXICO (Roswell)		REEVES Co. (Delaware-Castile)		SE. LEA Co. (Big Lime)	
		Lithology	Thickness	Lithology	Thickness	Lithology	Thickness
Quaternary		Caliche-Mescalero Ss.	0-250	Caliche-Bolson	0-25	Caliche-Mescalero Ss.	0-250
Triassic	Dockum Group	Red Beds	0-500	Red Beds	0-400	Red Beds	0-1500
Permian	"Pecos Valley Red Beds"	Red Beds & Gypsum	0-500	Red Beds-Some Gypsum	0-500	Red Beds-Some Gypsum	0-500
	Rustler-Castile-Carlsbad Group	Salt-Red Beds Anhydrite	0-1600	Dolomite-Anhydrite Salt Stringers	0-200	Dolomite-Anhydrite Salt Stringers	25-150
				Salt-Potash Anhydrite stringers	0-2500	Salt-Potash Anhydrite stringers	0-2000
				Anhydrite-Lime stringers Some Salt	200-400	Anhydrite-Sands	20-1200
				Clear Salt & Anhydrite	200-750	Anhydrite-Dolomite Stringers	
				Anhydrite & Limestone	50-400	Brown Dolomite Brown & Red Sands	
	Delaware Mt. San Andres Yeso Leonard (Bone Spring)	Dark Dolomite Ls.	400-1200	Dark Limestone	25-75	Dolomite & Gray Sandstone	100-300
		Coarse Grained Ss.	10-60				
		Brown & Red Shale-Some Salt-Anhydrite & Limestone	2000-2500	Fine-grained Sands-Limes-Some Shale	2000-2500	Light Dolomite	500-1700
	Abo Group	Dark Red Ss. & Shales Arkose & Conglomerates	750-1500	Black & Gray Limestone	800+		
Penn.	Magdelena	Limestone-Some Sand & Shale	550+				

FIG. 7.—Thicknesses shown in feet.

REEVES COUNTY (DELAWARE-CASTILE) SECTION

Skelly Oil Company's Leeman No. 1, north line Sec. 34, Blk. 75, Winkler County, Texas.
Humble Oil and Refining Company's Kloh No. 1, Sec. 33, Blk. 57, T. 1, Reeves County, Texas.
Superior Oil Company's Community No. 1, Sec. 33, T. 23 S., R. 28 E., Eddy County, New Mexico.

SOUTHWEST LEA COUNTY ("BIG LIME") SECTION

Getty Oil Company's Rawson No. 1, Sec. 14, T. 20 S., R. 29 E., Eddy County, New Mexico.
Artesia field, T. 18 S., R. 28 E., Eddy County, New Mexico.
Marland Oil Company's Eaves No. 1, Sec. 19, T. 26 S., R. 37 E., Lea County, New Mexico.
Hendricks field, Winkler County, Texas.

Along Pecos River in Eddy and Chaves counties, New Mexico, these three types of section may be found between the north line of T. 13 S. and the south line of T. 22 S.

The Bone Springs arch and the reef were the principal factors influencing the changes in lithology. Abrupt transition from sand into dolomite may be traced, partly on the surface and partly by subsurface, from Guadalupe Point along the escarpment to the vicinity of the city of Carlsbad. In Figure 8, the broken line defines the approximate location of the margin of the reef and is the line near which the change of facies takes place.

Wells on, or near, the edge of the reef are:

Gates and Holman's Murdock No. 1, Sec. 7, T. 21 S., R. 27 E., Eddy County, New Mexico.
J. S. Covert's State No. 1, Sec. 15, T. 21 S., R. 33 E., Lea County, New Mexico.
Marland Oil Company's Seideman No. 1, Sec. 4, T. 25 S., R. 36 E., Lea County, New Mexico.
White Eagle Oil and Refining Company's Leck No. 1, north line Sec. 30, Blk. 74, Winkler County, Texas.
Humble Oil and Refining Company's Ida Hendricks No. 1, Sec. 36, Blk. 27, Winkler County, Texas.
Benedum Trees' No. 1, Sec. 50, Blk. 8, Pecos County, Texas.
Southwestern Life Insurance Company's No. 1, Sec. 9, Blk. O W, Pecos County, Texas.
Humble Oil and Refining Company's McCutcheon No. 1, in Limpia Canyon, Jeff Davis County, Texas.
Humble Oil and Refining Company's Flores No. 1, Sec. 34, Blk. 58, T. 8, Jeff Davis County, Texas.

From the last-named well no further data are available until the Apache Mountains are reached, where the reef can be followed on the surface to the north end of this range. Between this locality and Guadalupe Point no further evidence of the reef is present.

In summary and in implication of the presence of similar sedimentational factors underlying or adjacent to the reef fringe as already

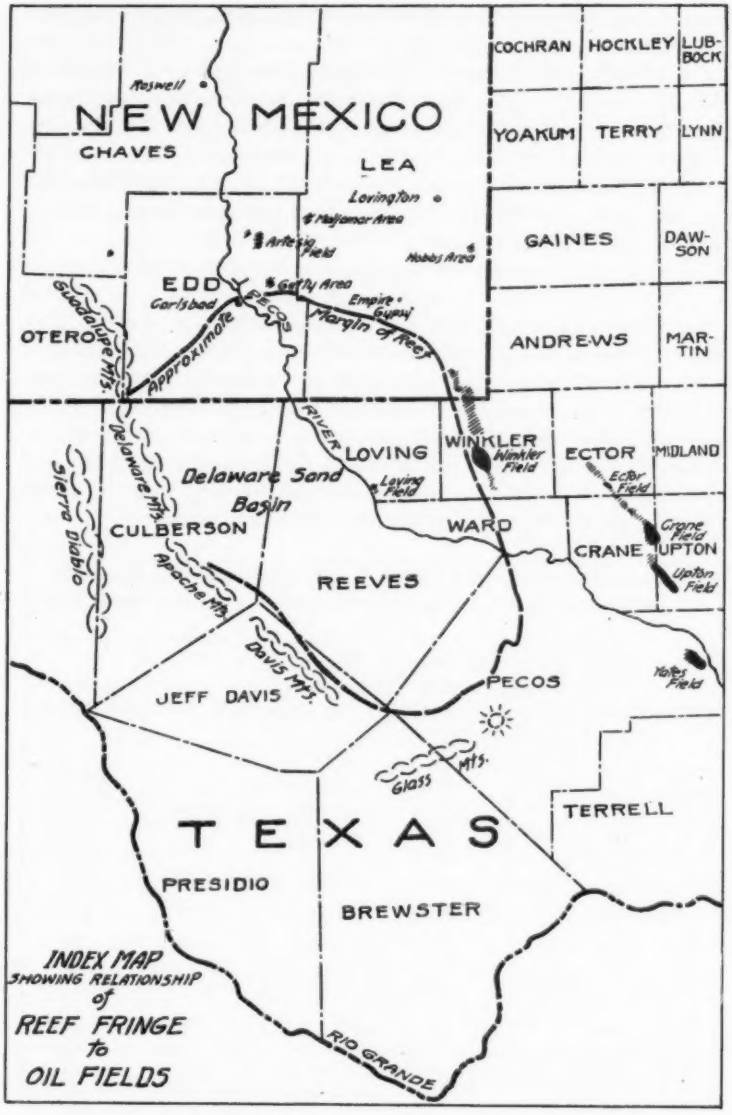


FIG. 8.—Width of area mapped, approximately 200 miles.

outlined, the following comparison between surface phenomena and available subsurface data is presented.

If the reader will consider that the dolomite escarpment from Carlsbad Caverns to Guadalupe Point and the Delaware Mountains immediately southward had been overlain with thick beds of anhydrite, salt, and red beds, he will have, in general, the same conception as that expressed by well records between the western part of the Hendricks pool and the Skelly Oil Company's Leeman No. 1, north line Sec. 34, Blk. 75, both in Winkler County, Texas.

As expected, connate waters encountered in wells in the upper part of the "Big lime" show considerable difference in chemical composition from those wells drilled into the Delaware Mountain sands. Much experimentation has been carried on regarding this subject in the Permian basin, and an exhaustive discussion of the use of water analyses in that area is not intended here. Figure 9 shows characteristic results.

"Big lime" waters contain appreciably greater percentages of sulphides, magnesium, calcium, and smaller amounts of total solids than those of Delaware Mountain sands. Deeper "Big lime" waters, analytically, approach those of the Delaware Mountain waters.

Comparison of Well Waters from the Big Lime and the Delaware Mtn. Sandstone of Southeast New Mexico and Present Day Sea Water.

Radicals	Marland Workman 1 S. 13 T. 22 S. R. 29 E. Delaware Sand 3212'	Marland Siedaman 1 S. 4, T. 25 S. R. 36 E. Mid. Big Lime 3830'	Texas Levers 4 S. 5, T. 18 S., R. 28 E. Lower Big Lime 3585'	Black Sea	Mid-Ocean
Cl	49.3	48.54	48.40	55.12	55.29
Na	48.7	30.03	47.59	30.46	30.26
CO_3	0.0	0.0	0.0	0.46	0.21
SO_4	0.6	1.4	1.54	7.47	7.91
Mg	0.3	11.66	0.54	3.74	3.89
Ca	1.2	5.34	1.86	1.41	1.24
HCO_3	0.01	0.06	0.06	---	---
P.P.M.	284,172	120,789	197,511	------	33,000

Note: Waters compared by reacting percentages.

FIG. 9

Returning to a discussion of the New Mexico area, it should be pointed out again that while the Yeso deposits were being laid down on the north side of the Bone Springs arch, in a restricted sea, marine Delaware Mountain sandstones were deposited on the south side. This will account for the lower parts of the three types of sections, that is, anhydrite, red beds, and salt north of the arch, solid limestone on the arch itself, and sands south of the flexure.

The influence of this arch continued through the next cycle—a reef was being built on it while sands were deposited on the south and marine limestones on the north. This was the San Andres, or second, period.

The next major change in section occurred during Carlsbad—Castile time, the third period. During this epoch the reef continued to grow on the flank of the Bone Springs arch, but the waters reached a state of concentration at which anhydrite as well as limestone was being precipitated, the two being interbedded. It is interesting to notice that the high escarpment from Carlsbad to Guadalupe Point is caused by both the sudden transition of sand to more resistant dolomite and the transition from interbedded limestone and anhydrite to the solid reef dolomite of Carlsbad.

Since the close of Carlsbad-Castile deposition, no striking dissimilarities of sedimentation were found on opposite sides of the Bone Springs arch.

It is hoped that the data presented regarding the true relationship between the upper Delaware Mountain formation and its Capitan dolomite expression will clarify a long-disputed point with regard to the age and correlation of the "Big lime" of eastern New Mexico and western Texas.

In view of the many discussions in which the writers have expressed themselves regarding this subject, it may be well to state that the "Big lime"-Capitan correlation at one time offered by them was the result of tracing the Queen sand zone from the Artesia field southwest into the Capitan dolomite at its type locality, it being far easier to reach the type locality from the north than from any other direction. It has now been established that not only is the "Big lime" equivalent to the Capitan, but also that the major part of the Capitan is the dolomite phase of the Delaware Mountain formation.

Although the presentation of a detailed description of the present structural arrangement in the Permian salt basin is beyond the intended scope of this paper, some reference thereto is necessary because of the large producing oil fields adjacent to the reef fringe.

The Getty pool in T. 20 S., R. 29 E., the producing area in the vicinity of Jal, New Mexico, the Leck area in northern Winkler County, Texas, and the main Hendricks pool in the same county are located near the margin of the reef. David White[1] has identified fossil forms found in Winkler County cores as colonial algae resembling *Girvanella*.

The main producing zones commonly occur in massive white dolomite nearly everywhere associated with a cavernous condition. A sandy section that assumes an almost characteristic Delaware Mountain sand facies occurs above the white dolomite. Ordinarily only large volumes of gas occur in it, the oil being in the more porous dolomite below.

These accumulations along, and within, this great reef are thought to be due to a combination of depositional phenomena and structural movements. The physical peculiarities of reef masses such as "flow" planes and the original skeletal and cavernous nature of the reef masses, as described by Clarke,[2] are thought to explain adequately the present character of the producing zone. Deformation after deposition has also, undoubtedly, had much to do with the same condition.

From the subsurface data there is positive evidence that movement and oscillation have continued from before the beginning of Delaware Mountain deposition to the close of Triassic time.

For a long period during and following Delaware Mountain sedimentation, the area enclosed within the elliptical reef margin, sometimes called the Delaware Basin, was a negative area. The great thickness of beds bears witness to its slow down-warping.

At the beginning of the upper salt deposition, the reef also became involved in the downward swing of the Delaware Basin, while the areas on the sides of the reef away from the basin remained comparatively stationary. As a result of this situation, thicker bodies of salt were deposited in the Delaware Basin and on the reef than were laid down over the areas surrounding them.

As a result of these long-continued oscillations, it was inevitable that folds should be arranged *en échelon*, in systems or trends in which the present accumulations are found.

DISCUSSION

ROBIN WILLIS, Midland, Texas: I should like to ask Mr. Blanchard if there is any evidence of unconformity between the Delaware formation and the Bone Springs limestone?

[1]Letter to Lon D. Cartwright, Jr.

[2]*U. S. Geol. Survey Bull. 770*, 5th ed., p. 576.

W. GRANT BLANCHARD: Perhaps Dr. Keyte can give us some information on this subject.

I. A. KEYTE, Colorado Springs, Colorado: I do not know of any specific evidence and can not answer this question.

ROY H. HALL, Wichita, Kansas: I believe there is good evidence of unconformity between the Delaware formation and Bone Springs limestone (Fig. 10). Along the northwest face of Bone Springs Canyon the basal conglomerate of the Delaware formation includes rounded boulders and other débris from the underlying black and gray members of the Bone Springs limestone. Further evidence of unconformity may be seen in the rapid thinning of the Delaware northward against the eroded face of the Bone Springs limestone.

W. GRANT BLANCHARD: The conglomerate at the base of the Delaware formation in Bone Springs Canyon does contain débris of the underlying black limestone. This conglomerate, however, is local in extent and farther north the contact shows very little real conglomerate.

FIG. 10.—Unconformity between Delaware formation above and Bone Springs limestone (Leonard) below. Also basal conglomerate of Delaware formation can be plainly seen marked by arrow at right.

PRELIMINARY CORRELATION OF THE TEXAS AND NEW MEXICO PERMIAN[1]

ROBIN WILLIS[2]
Midland, Texas

ABSTRACT

The stratigraphy of the outcrops and of the subsurface of the Texas and New Mexico Permian formations is summarized. Four geographical divisions are considered, namely, the Panhandle arch, the main western Texas and eastern New Mexico basin, the Guadalupian barriers, and the trans-Pecos basin. Formations are correlated within each basin, and the problem of correlating across the Guadalupian barriers is discussed. Oil-bearing formations are tentatively correlated with surface formations. Finally a systematic summary of the stratigraphic history of the Permian of this region is attempted.

Much work has been done in reconnaissance, in detailed surface mapping, and in subsurface study, on the Permian formations of Texas and New Mexico. Few attempts have been made, however, to piece together the history of the Permian basin as a whole. Correlations made by means of fossils differ from those made by the tracing of outcrops and observation of formational gradations. Subsurface information has increased greatly in the past two years. In addition to this, certain papers have been published or are now in press which greatly clarify relationships in areas where outcrops are plentiful but where correlations are obscure. The object of this paper is to consider all such evidence, including both surface and subsurface information, in an attempt to outline a systematic history of the Permian of this region, and in so doing to correlate the various formations exposed around its borders with one another and with the subsurface sections.

ACKNOWLEDGMENTS

The writer has been fortunate in his association with men who were thoroughly conversant with the surface geology of all of the Permian outcrops (Fig. 1) of the region under consideration. He has not himself made an extensive study of these outcrops. So far as they are con-

[1]Read before the Fort Worth meeting of the American Association of Petroleum Geologists, March 21, 1929, under the title "Stratigraphic Controls in the West Texas Permian." Manuscript received by the editor, May 8, 1929.

[2]Consulting geologist.

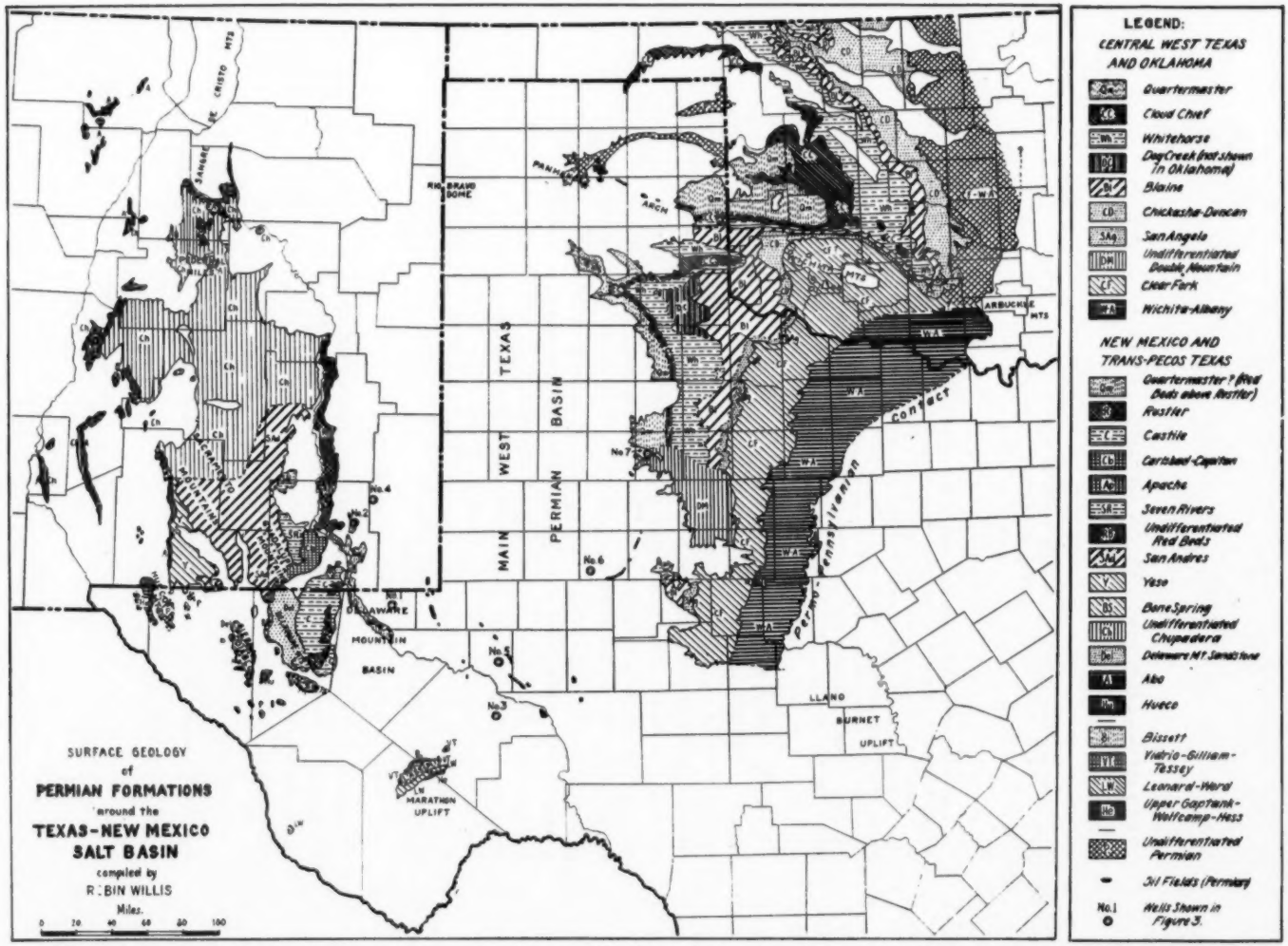


FIG. 1.—Outcrop map of the Permian formations around the Texas and New Mexico basin. Compiled from the following sources: U. S. Geological Survey, State Geological Map of Oklahoma; U. S. Geological Survey, State Geological Map of New Mexico; Bulletins of the Bureau of Economic Geology of Texas and the State Geological Map of Texas; Map of Southeast New Mexico and Trans-Pecos Texas, furnished by W. G. Blanchard, Jr., and M. J. Davis; field work by the writer.

cerned, therefore, this work is one of compilation. He wishes to express his indebtedness to W. G. Blanchard, Jr., H. L. Baldwin, Jr., and I. A. Keyte, whose work in the Glass Mountains, the Guadalupe Mountains, and the region adjoining them has resulted in the correlation of the formations there exposed. The correlation of the New Mexico outcrops has been aided by discussion with Morgan J. Davis, F. S. Prout, and K. H. Crandall. The subsurface correlation of the Panhandle district was made possible by the coöperation of J. J. Maucini and J. V. Howell, while the writer's introduction to the study of the subsurface of West Texas was made with the help of D. D. Christner and C. D. Vertrees. Finally, he owes much to E. Russell Lloyd, who first demonstrated to him the reef character of the Capitan limestone and outlined the conditions which must have existed during its formation.

DIVISIONS OF THE PERMIAN BASIN

There are five principal divisions of the Permian basin, three basins and the transition zones between them. These are the Kansas and Oklahoma basin, the main western Texas and eastern New Mexico basin, and the trans-Pecos Texas basin, with the Panhandle arch between the first two and the Guadalupian barriers between the last two. This paper deals only with those parts of the basin south of the Panhandle arch. Correlations are comparatively simple within the basins, and these will be taken up individually. The evidence exposed in the Guadalupe Mountains will then be considered, and an attempt made to correlate across it and its associated barriers between the two basins.

MAIN WEST TEXAS AND EASTERN NEW MEXICO BASIN

CENTRAL TEXAS AND SOUTHWEST OKLAHOMA OUTCROPS

The Permian outcrops on the east side of the Permian basin extend from Kansas into Oklahoma, around the north and west sides of the Wichita Mountains and south into Texas, dipping westward under the Triassic into the West Texas basin, and disappearing below the Comanche south of Colorado River. The Texas formations are classified in the following section.

Quartermaster
Cloud Chief
Whitehorse (Lake Trammell)
Dog Creek
Blaine (Eskota-Medicine Mound)
San Angelo
Clear Fork
Wichita-Albany

Geological Map of Texas; Map of Southeast New Mexico and Trans-Pecos Texas, furnished by W. G. Blanchard, Jr., and M. J. Davis; field work by the writer.

The Oklahoma equivalents are shown in the correlation chart (Fig. 2). It is not necessary to describe more than the one section, with the exception of the Chickasha formation which lies between the San Angelo and the Blaine.

The Wichita-Albany formation (Fig. 3) is the oldest of the Permian series, lying apparently conformably on the Cisco. The Wichita Red-beds grade south from the Wichita Mountains, from arkosic sandstone through maroon and chocolate-colored shale and sandstone into the blue shale and limestone of the Albany beds. The Wichita Red-beds are much less extensive than the Red-beds of the Cisco below them. In the uppermost part of the formation between the Lueders limestone and the Standpipe limestone the shales retain their red color farther south than the beds below them, indicating a transitional zone between the restricted Red-beds of the Wichita-Albany and the more extensive Red-beds of the Clear Fork.

The Clear Fork formation (Fig. 4) consists chiefly of brick-red shale with occasional dolomite beds. The latter are prominent in the south but practically disappear northward before Red River is reached. Southward the red shales grade into blue shales in the vicinity of Colorado River.

Both the Wichita-Albany and the Clear Fork grade from red to non-red and from shale to limestone westward in the subsurface as well as southward along the outcrop.

One of the few recognizable unconformities in the Permian is found at the top of the Clear Fork. This has been described by Beede.[1] It is overlain by the San Angelo sandstone and conglomerate. This formation grades from coarse conglomerate at San Angelo to sandstone and shale toward the north. This gradation is in the opposite direction from that of the underlying formations. The gradation to shale toward the west, however, corresponds with that of the older beds. The sea, therefore, lay on the west at both times, but the principal source of the Wichita clastic sediments seemingly was on the north, while the Llano-Burnet region was of more importance in San Angelo time.

The San Angelo can be traced northward into the Duncan in Oklahoma.[2] Above the Duncan lies the Chickasha formation, a typical salt deposit of red clastics and desiccation deposits, which slumps readily at

[1] J. W. Beede and W. P. Bentley, "Geology of Coke County, *Univ. of Texas Bull. 1850* (1918), p. 49.

[2] C. N. Gould, "Correlation of the Permian in Kansas, Oklahoma and Northern Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 144-53.

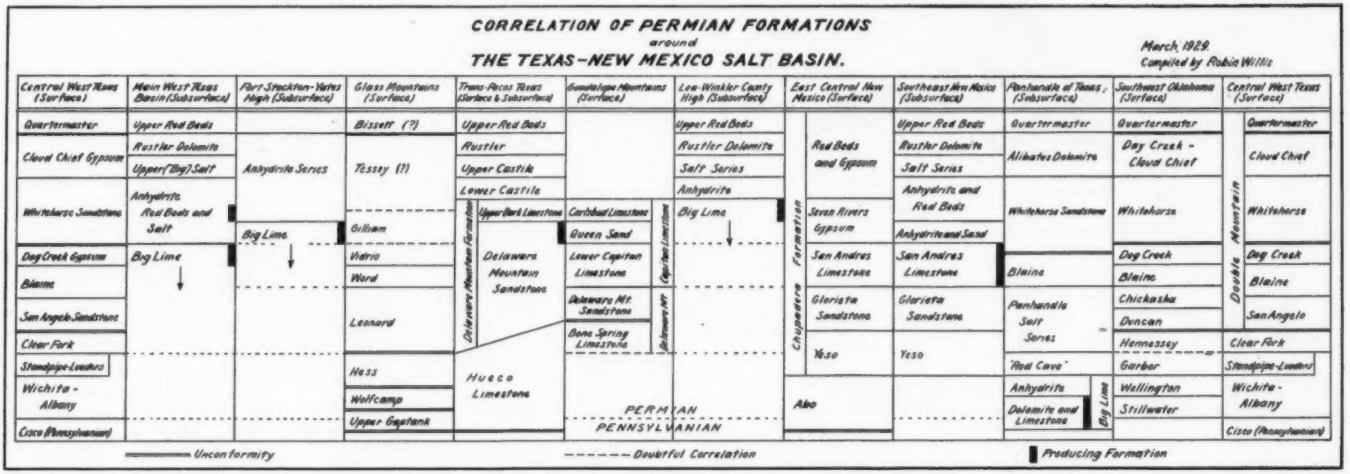


FIG. 2.—Correlation chart of the vicinity of the Texas and New Mexico salt basin.

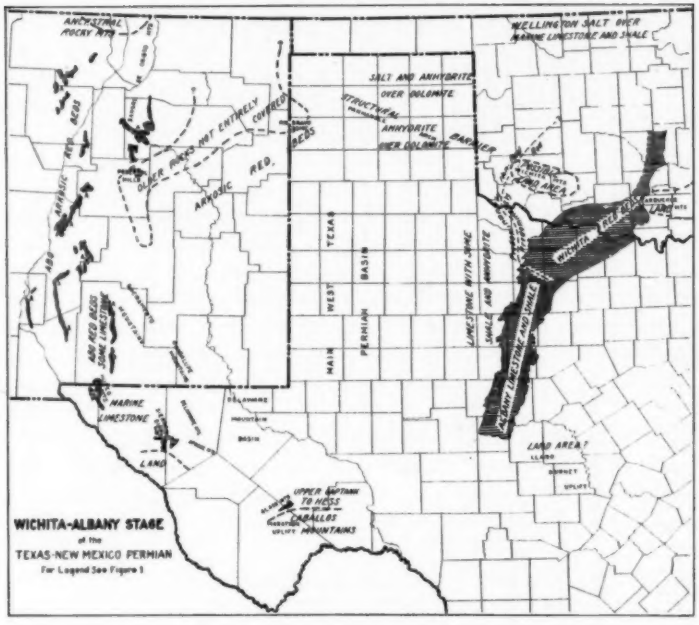


FIG. 3.—Outcrop of the Wichita-Albany formation, and of formations correlated with it, and stratigraphy of their subsurface equivalents.

the surface, suggesting that salt has been leached from it. In Texas this formation has not been defined, but the writer has observed a shaly zone between the uppermost sandstone of the San Angelo and the lowermost dolomite beds of the Blaine. This interval probably corresponds with the Chickasha.

The Blaine (Fig. 5), a gypsum, dolomite, and red shale series which overlies the Chickasha in Oklahoma and the San Angelo in Texas, furnishes the most continuous series of outcrops of any Permian formation. It can be traced from Kansas around the Anadarko Basin in central Oklahoma and south past the Wichita Mountains to San Angelo in Texas. Individual dolomite beds can be traced for a considerable part of this distance. The gradation is toward relatively less saline conditions and fewer clastic sediments on the southwest. The red shales are less prominent, and the dolomite beds much more prominent, in the southern part of the outcrops in Texas.

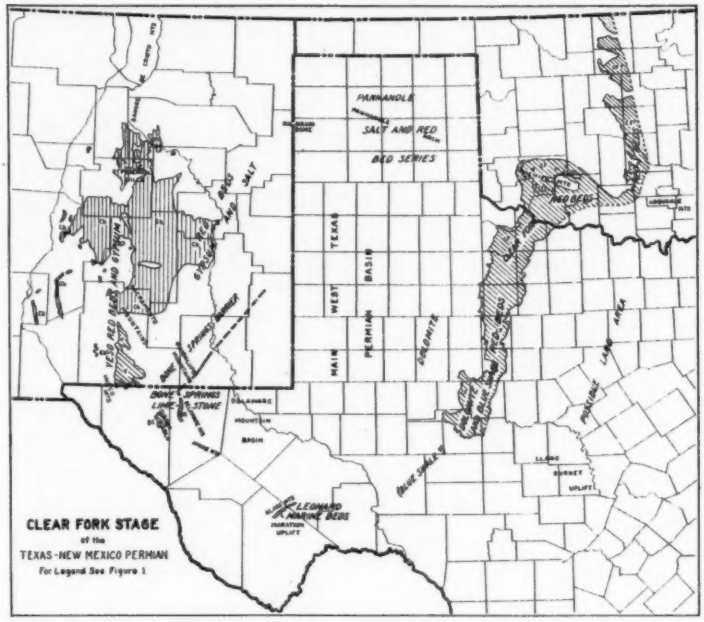


FIG. 4.—Outcrop of the Clear Fork formation, and of formations correlated with it, and stratigraphy of their subsurface equivalents.

Above the Blaine in Oklahoma, and in the area just south of the Texas Panhandle, is found a formation composed of red sand and shale and gypsum, but carrying no dolomite. This is known as the Dog Creek. It is missing in places, probably cut out by an unconformity.

The Whitehorse sandstone (Fig. 6) which overlies the Dog Creek and the Blaine is a very fine, uniform red sandstone which carries a few stringers of gypsum. On the south flank of the Panhandle arch in northern Childress County, the writer has observed this formation lying directly on beds well below the top of the Blaine. The Aspermont dolomite (the uppermost member of the Blaine) and part of the section below it, as well as all of the Dog Creek, are missing. In central Cottle County the Whitehorse rests directly on the Aspermont. The unconformity indicated by these facts is probably connected with the uplift that changed deposition from shale, gypsum, and dolomite to sand.

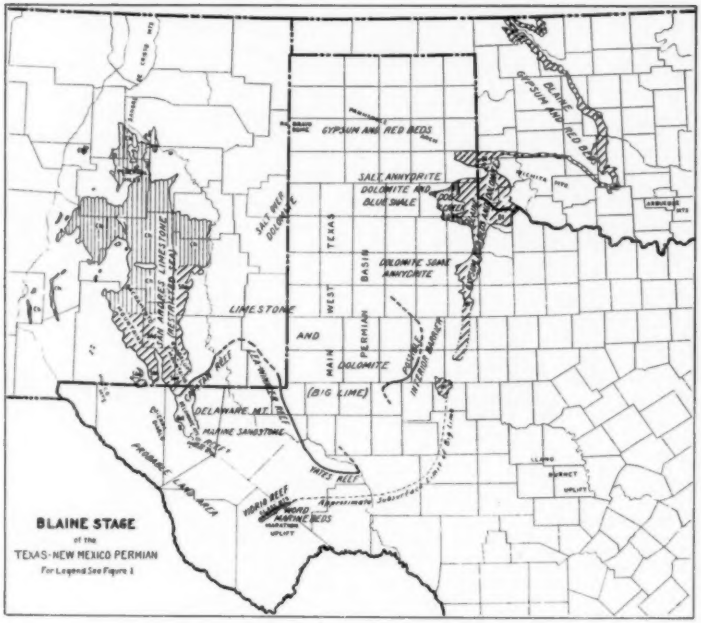


FIG. 5.—Outcrop of the Blaine and Dog Creek formations, and of formations correlated with them, and stratigraphy of their subsurface equivalents.

Above the Whitehorse lie the Cloud Chief gypsum and the Alibates dolomite (Fig. 7). These seem to be equivalent, the Alibates being found on top of the Panhandle arch and the Cloud Chief on its flanks. This gradation seems to be connected with structure rather than with the direction of the open sea. Other examples of chemically precipitated beds which grade to a less saline deposit over the top of a structure or where the water was shallower will be cited later.

The Quartermaster formation, the youngest of the exposed Permian beds of the Mid-Continent region, is found above the Cloud Chief and the Alibates. It is mainly a thin-bedded brick-red sandstone with occasional white streaks. An unconformity at its base is reported in Oklahoma.

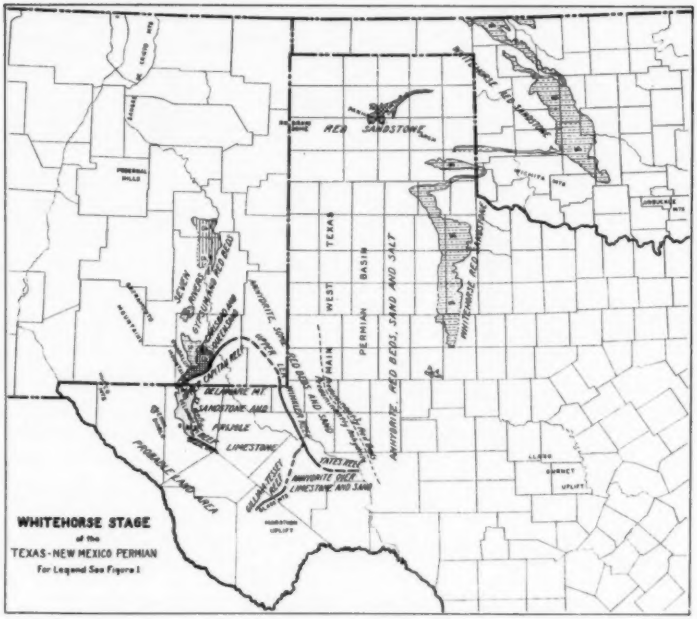


FIG. 6.—Outcrop of the Whitehorse formation, and of formations correlated with it, and stratigraphy of its subsurface equivalents.

THE PANHANDLE OF TEXAS SECTION

The subsurface correlation of the Panhandle of Texas is comparatively simple. The section is divided into the following units.

Quartermaster
Alibates dolomite
Whitehorse sandstone
Blaine gypsum
Panhandle salt series
"Red Cave"
Panhandle "Big lime"
- Anhydrite
- Dolomite
- Limestone
- Granite wash

} Pay horizons

Development has progressed in the Panhandle region and the area south of it and on the west end of the Red River arch to a point where

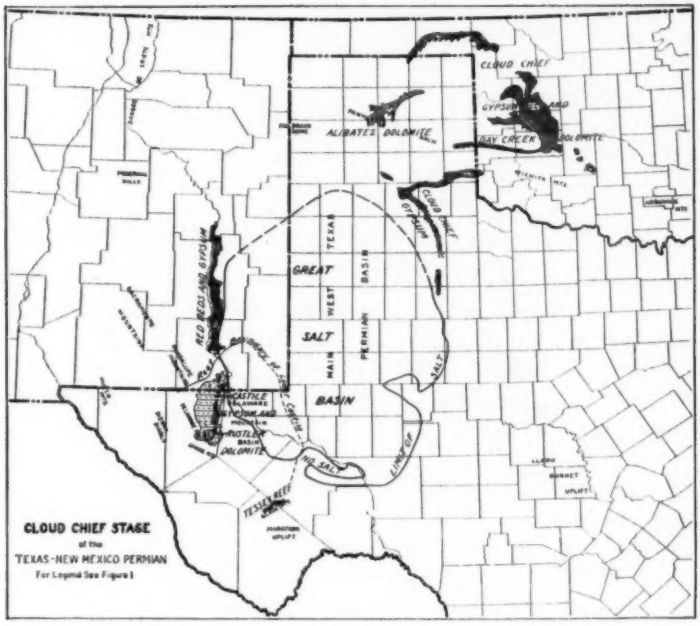


FIG. 7.—Outcrop of the Cloud Chief formation, and of formations correlated with it, and stratigraphy of its subsurface equivalents.

there can be no question concerning the correlation of the Panhandle "Big lime." The Coleman Junction limestone at the top of the Cisco can be traced in the subsurface practically into the Panhandle.

The uppermost Red-beds of the Cisco 200 or 300 feet below the Coleman Junction do not extend quite so far. They grade into blue shale and finally into limestone in Foard, Cottle, and Childress counties. Red beds just below these, however, extend through and can be traced directly into the granite wash on the south flank of the Panhandle arch. Above the Cisco the Wichita beds grade westward into limestone, dolomite, and anhydrite, and can be traced into the main body of the Panhandle "Big lime." The contact between the Pennsylvanian and the Permian in the Panhandle is placed, therefore, a short distance above the top of the granite wash, the lowermost limestone corresponding with the Coleman Junction and the beds just below it. Most of the Panhandle

"pay" is probably Pennsylvanian, though the porous top part may be correlated with porous horizons in the lower Wichita-Albany which carry water throughout the area west of the Bend arch.

Anhydrite is found in wells drilled through the Wichita-Albany all the way from Runnels County to the Panhandle. This occurs in the upper part of the section and increases toward the north. In a very few wells salt has been found. These deposits can be traced directly into the anhydrite section of the Panhandle "Big lime". North of the arch these beds carry salt, and are correlated with the Wellington of Kansas.

The fact that the Cisco Red-beds are more extensive than those of the Wichita-Albany has already been noted. The correlation of the non-red "Big lime" with the Wichita-Albany and of the red Granite wash with the Red-beds of the Cisco, is, therefore, logical.

The top of the non-red Albany series in the southern part of its outcrop is the Standpipe limestone. Farther north the Lueders limestone is the topmost member below the Red-beds. The Red-beds between these two are of importance as they can be traced directly into the so-called "Red Cave" of the Panhandle subsurface. This "Red Cave" is a soft cavey red shale impregnated with salt. It can be traced across the Panhandle into New Mexico and its base apparently corresponds with the base of the Yeso.

The Clear Fork, San Angelo, and Chickasha formations can be traced directly into the Panhandle salt series. The San Angelo is lost in the subsurface westward across the Panhandle. It lies near the middle of the salt series.

Above the Chickasha formation the Blaine, carrying as it does non-red beds of gypsum, dolomite, and blue shale, can be followed with little difficulty across the Panhandle into northeast New Mexico, where it is correlated with the San Andres.[1]

The Dog Creek is thought to be missing on top of the Panhandle arch, due to the unconformity already noted between it and the Whitehorse. It has not been traced in the subsurface; therefore it is doubtful whether the top of the Blaine or the top of the Dog Creek is equivalent to the top of the San Andres.

The Cloud Chief gypsum and Alibates dolomite both crop out in the Panhandle. They correspond with the Cloud Chief and Day Creek of Oklahoma. The beds above them are similar in character to the Quartermaster and are correlated with it.

[1]C. N. Gould and Robin Willis, "Tentative Correlation of the Permian Formations of the Southern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927), pp. 431-42.

EAST-CENTRAL NEW MEXICO SECTION

The section of Permian beds in east-central New Mexico includes the following formations.

Upper Red-bed series San Andres limestone Glorieta sandstone Yeso Red-beds Abo	Chupadera[1]

The Abo (Fig. 3) is a series of maroon-red sandstone and shale. The sandstone is arkosic, particularly on the north and west near its source. In its extreme southern extent, the Abo carries beds of marine limestone, and it probably grades south into part of the limestone series of the Hueco Mountains. The outcrop cannot be traced continuously, due to faulting, but the limestones on the south extend both above and below the Abo, hence they probably include beds of Abo age.

Westward across the Panhandle, the "Big lime" grades rather abruptly into red beds around the Rio Bravo dome. The gradation is similar to that of the Wichita into the Albany. These red beds have the characteristics of the Abo. This formation is therefore correlated with the Wichita, and the limestone facies in the Hueco Mountains is equivalent to the Albany.

The color of both the Abo and the Wichita is maroon-red or variegated. At the top of each there is a marked color change. The Yeso beds (Fig. 4) which overlie the Abo are made up of purplish red shale with some sandstone and numerous beds of gypsum with some black limestone. Salt is logged in wells, and salt flats give evidence of it at the surface. This formation can be traced eastward into the lower Panhandle salt series and the "Red Cave," and is probably equivalent to the Clear Fork and to that part of the Wichita-Albany between the Lueders and the Standpipe limestones. This is a logical correlation, as the Clear Fork salt basin extends south of the Panhandle arch, at least as far as the western extension of the Red River arch, and salt would be expected still farther south in New Mexico as there is no barrier to cut it off. The barrier which it is thought did separate the Yeso basin from marine conditions lies in the Guadalupe Mountains, and will be discussed later.

Above the Yeso lies the Glorieta sandstone. This formation is nearly uniform in character throughout wide areas. It is interbedded with the

[1]Though the Yeso, Glorieta, and San Andres are not recognized by the U. S. Geological Survey, being grouped in the Chupadera formation, each of the three deserves the rank of formation, as each is a mappable unit throughout a large part of New Mexico. It is impossible to discuss the Permian history of this region without referring to these as separate units.

lower limestone of the San Andres in the north, and pinches out on the south in the Guadalupe Mountains. In the subsurface it can be traced eastward more than half-way across the Panhandle, maintaining a thickness of 500 feet until it grades into the upper part of the Panhandle salt. Its base is near the position inferred for the San Angelo, though the two cannot be brought together. The Glorieta is therefore approximately equivalent to the San Angelo and the Chickasha.

The San Andres limestone (Fig. 5) is a black or brown limestone which locally grades into gypsum. It has been correlated with the Blaine, as already stated, and with it makes the best marker for correlating the Permian beds around the main western Texas and eastern New Mexico basin.

Above the San Andres is a series of red shale, sandstone, and gypsum. This has not been subdivided. The name Seven Rivers gypsum (Fig. 6) has been given to the beds exposed south of Roswell,[1] but these beds probably do not include all of the series exposed in the eastern part of the state.

The whole series is equivalent to the Whitehorse, Cloud Chief, and Quartermaster of Texas. Westward across the Panhandle these formations lose their identity and can not be differentiated on the outcrop in New Mexico.

SUBSURFACE GRADATIONS IN WEST TEXAS AND SOUTHEASTERN NEW MEXICO

Before considering the correlation of the different subsurface sections of the western part of the main Permian basin, it is necessary to discuss the gradations which are found in the sediments and their effect upon the stratigraphic markers.

The most important gradation is that of the chemically deposited sediments. This depends upon variations in salinity of the waters. The observed sequence is as follows, from less saline to more saline deposits: normal marine limestone, white secondary dolomite (porous), brown primary dolomite (non-porous), anhydrite, and salt.

Salinity can be influenced by two factors. When a barrier is crossed into an enclosed basin, the waters may become rapidly more saline and the above gradation may be traced horizontally through a comparatively short distance. It is also possible for the explorer to encounter more saline waters as he goes inland in a long arm of the sea, or as he approaches

[1]Oscar Meinzer, B. C. Renick, and Kirk Bryan, "Geology of No. 3 Reservoir Site of Carlsbad Irrigation Project, New Mexico, with Respect to Water Tightness," *U. S. Geol. Survey Water Supply Paper 580-A* (1926).

the shore over widespread shallows. In the latter case it is seemingly not necessary to have a marked barrier.

Certain characteristics of clastic sediments seem to be associated with certain types of chemical sediments. Thus all shales and sandstones which occur interbedded with white dolomite or limestone are blue, gray, or maroon-red. Clastic sediments associated with brown dolomite or with anhydrite are much more rarely non-red and are brick-red rather than maroon-red. Bentonite is found in several parts of the section. Wherever it is associated with white dolomite, it is, as a rule, pale green in color. Where it occurs with anhydrite, it is green in some places, but is more generally red or purplish black.

The gradation of chemical sediments and the color of associated clastic sediments previously described may occur either horizontally or vertically. A combination of the two gives an inclined line of change. Nearly all formational gradations due to changing conditions through a period of time show the upward gradation from limestone through dolomite into anhydrite. It is possible, therefore, to duplicate this sequence in different parts of the basin in formations of different ages. It is difficult to find reliable markers throughout a wide area, and near a barrier where the change may be both horizontal and vertical, the observer may seem to be following a single horizon when he is actually moving up or down through the section, depending on whether he is approaching or leaving the barrier.

POROSITY

In the sequence of chemical sediments already outlined, it is suggested that porous horizons which occur a certain distance below the top of a lime section may be due to changing conditions which at a certain point favor dolomitization which produces porosity. Porosity may be formed in other ways. A seeming relationship between porosity and structure[1] leads to the suggestion of possible unconformities which permitted leaching on the structural "highs" with resulting local porosity. The porous horizons of the San Andres limestone in southeastern New Mexico retain their position in the section over wide areas. They may be connected with the formation of chert or with other depositional conditions which are not limited or controlled by structure. Finally, the relation of porosity to reef development has been pointed out by E. Russell Lloyd.[2]

[1]Ben C. Belt, "Tectonics of West Texas and Eastern New Mexico." Manuscript presented before the American Association of Petroleum Geologists at the Fort Worth meeting, March 22, 1929.

[2]E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929).

Where great thicknesses of limestone are found to be porous throughout their vertical extent, and where this porosity is limited areally to a narrow belt, the formation in which it is found is probably a reef.

SUBSURFACE SECTION OF THE MAIN WEST TEXAS BASIN

All of the Permian beds found in the main basin north of the transition zone of the Guadalupian barriers may be divided into the following units.

Uppermost Red-beds
Rustler
Main salt series
Anhydrite and red-bed series
"Big lime"

Below the "Big lime" in eastern New Mexico, the Glorieta sandstone and the Yeso and the Abo Red-beds can be recognized, and in Crockett, Irion, and Reagan counties in the southern part of the basin there is a thick shale series below the lime. The correlation of this shale series is perhaps subject to more question than any other correlation in West Texas at the present time. It may be anything from middle Pennsylvanian to Double Mountain age. The "Big lime" is much thinner in the areas where this shale series is found than it is farther north and west. Three possibilities may be outlined in regard to it. The section may not change its thickness, but the dolomites of the lower "Big lime," including the Wichita-Albany, Clear Fork, and possibly the Double Mountain beds below the Blaine may grade into shale toward the south. If they do so grade, the shale is probably derived from the old land mass extending between the Marathon uplift and the Llano-Burnet uplift. The second possibility is that these shales are Pennsylvanian and that the early Permian deposits were not deposited, or have been eroded from the area where the shales are found, the Blaine overlapping them and resting directly on the shales. The third possibility is that the "Big lime" over the shales is of early Permian age, and that the Double Mountain part of the "Big lime," and possibly the Clear Fork, have been eroded off over a structural "high." As the evidence is inconclusive, these shales are not shown on the correlation chart.

The "Big lime" is the most important formation in West Texas, as the bulk of the production comes from it. Its normal thickness is approximately 3,000 feet. From Tom Green to Dickens counties it has been penetrated, and it can be subdivided and correlated with the surface formations on the east by careful subsurface correlation and the use of sam-

ples. It includes the Wichita-Albany, the Clear Fork, the San Angelo, the Blaine, and probably the Dog Creek (Fig. 8). The first shales below it in Tom Green County are probably 300 feet down in the Cisco, hence it includes a little Pennsylvanian as well. The San Angelo can be traced westward by samples as far as Borden County. The interval above it to the top of the lime varies somewhat. The writer believes this is due to the unconformity at the base of the Whitehorse.

The correlation of the top of the lime has been much discussed. It is not always an exact marker, as the gradation from limestone through porous and non-porous dolomite into anhydrite is ordinarily found, and alternations from dolomite to anhydrite and back are common. In the southern part of the basin, the break between lime (dolomite) and red beds is fairly satisfactory, but toward the north red beds appear below the uppermost solid dolomite. Still farther north, in Garza County, the uppermost dolomite grades into anhydrite. In general, however, the upper part of the "Big lime" is non-red, and may be correlated with the gypsiferous and dolomitic Dog Creek and Blaine. The Dog Creek may be missing in places, as suggested above, but probably, where the sequence is complete, the top of the lime lies at the top of the Dog Creek.

On the west side of the basin, in the Artesia district and farther north, in Chaves County, the top of the lime can be traced directly to the top of the San Andres. Here also it is difficult to determine an exact point, because of the intergradation of the lime with the anhydrite above it. Farther north, in Roosevelt County, the upper part of the lime grades into salt, just as it does into anhydrite north of Garza County. This may be the Dog Creek, as this formation is more saline than the Blaine. The San Andres, therefore, probably includes both the Dog Creek and the Blaine.

The top of the lime referred to in the foregoing paragraphs applies only to the part of the basin north of the Lea-Winkler and Fort Stockton-Yates "highs." On these "highs" the top of the lime is higher in the section. They form part of the Guadalupian reef barriers, and will be discussed later.

There is also a possibility that the other limestone "highs" of the basin, notably the Mitchell and Howard County "high" and the McCamey-Church and Fields-Waddell-Connell "high," are depositional "highs," built up as reefs or current deposits above the general level of San Andres-Blaine deposition, or formed over these formations as current deposits or limestone deltas in the more saline Whitehorse sea. Due to the continuity of the various horizons in the top of the lime on and off of

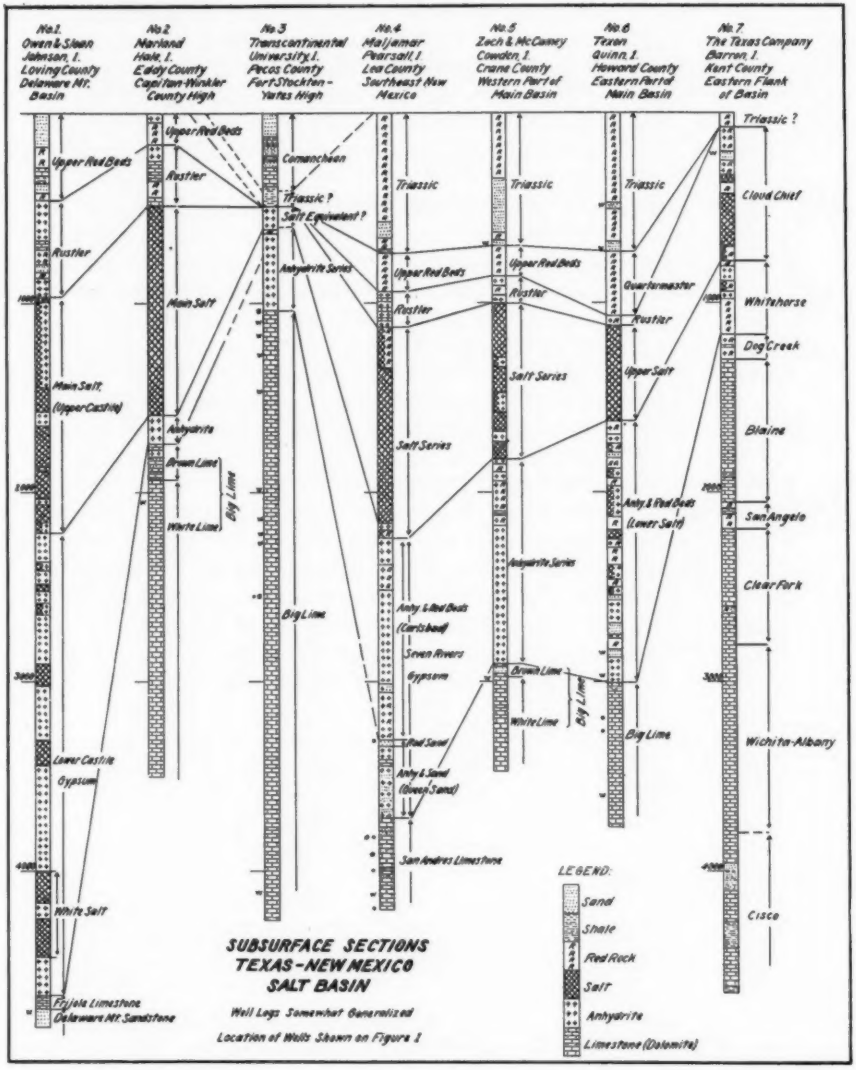


FIG. 8.—Comparative subsurface sections of the Texas and New Mexico Permian, taken from typical well logs, and showing correlations.

these "highs," however, the writer is inclined to regard them as structural features, and believes the burden of proof is on anyone wishing to show that they are reefs or depositional "highs." They lie within the reef barriers of the Lea-Winkler and Fort Stockton-Yates "highs," and it is difficult to see how they could have been built as reefs in the more saline waters of the enclosed basin, though the current and delta theories are worthy of consideration.

The production of the Artesia and Maljamur pools comes from porous streaks in the San Andres. These range throughout the section, and do not appear to be connected with the gradation from limestone to dolomite. The McCamey and Church and Fields pools produce from the upper part of the lime, and the porous horizons in them fit into the sequence from limestone through secondary porous dolomite into brown non-porous primary dolomite. This is also true of the Powell field.

The Big Lake pool is a special pool in which the production is obtained from oölitic horizons near the top of the lime. In Howard, Mitchell, and Scurry counties, the lime production is found near the top of the lime, in beds of Blaine age, and also lower in the section, in the San Angelo and even in the Clear Fork. The principal production at the Westbrook pool comes from the last named formation.

The anhydrite and red-bed series shows three distinct facies in different parts of the basin. East of the axis of the basin it is composed mainly of sand, red beds, and salt. This series can be traced directly into the Whitehorse at the surface. It carries the shallow pay horizons of Howard County and the 2,400-foot "pay" at Big Lake. These produce sweet oil from sand.

In southeast New Mexico this series is mostly anhydrite. In the upper part there is one break of red shale, which occurs about 100 feet below the salt, and the lower half of the series carries several sand horizons in which oil showings are found. The uppermost of these is known as the Red sand in the Artesia and Maljamar districts, and is a reliable structural marker.

In the area between the McCamey and Fort Stockton "highs," in northern Pecos and Crane and eastern Ward counties, the series is almost entirely anhydrite, there being much less sand in the lower part and only a little red shale near the top.

The main salt series extends throughout the whole of the southern part of the basin, as well as across the Guadalupian barriers into the Delaware Mountain basin. On the west it is capped by the Rustler series of dolomite and anhydrite. This is missing on the east, but a few

gypsum beds come in above the salt in Kent County near the outcrop. These seem to correlate with the Cloud Chief at the surface. The whole of the Rustler and salt series may be equivalent to the Cloud Chief, or the salt may be a lens below the Cloud Chief, which wedges out eastward toward the edge of the basin. It can be shown to wedge out under the Rustler on the west side.

Throughout the whole basin the uppermost Permian beds are red sand and shale which show little variation in character from Oklahoma to Pecos River. These comprise the Quartermaster formation. There is probably an unconformity at their base, which accounts for the absence of the Rustler in the eastern part of the basin.

An alternative correlation to that given above was suggested to the writer by R. K. DeFord,[1] who has traced the salt series north to the Panhandle on the west side of the basin. He thinks that another salt series comes in below the main southwest Texas salt, in the upper part of the red-bed section, and that this series is equivalent to the Alibates dolomite or the Cloud Chief. This would put the Cloud Chief below instead of above the main salt, which with the Rustler would be missing in the unconformity below the Quartermaster in the Panhandle and on the outcrop in Texas. He suggests that only the lower or sandy portion of the anhydrite series in southeastern New Mexico is equivalent to the Whitehorse and that the upper half is equivalent to the Cloud Chief. The writer favors the first correlation, because of the relations shown in Kent and Dickens counties, but he does not regard this as proved, and the other possibility should be given full consideration.

THE TRANS-PECOS TEXAS BASIN

The formations of Permian age which outcrop in trans-Pecos Texas are entirely distinct from those found in central Texas and eastern New Mexico, and the correlation of the two areas has never been entirely satisfactory. Paleontological correlation has not agreed with the field evidence in the Guadalupe Mountains, the only area where the two are brought into juxtaposition. We know now that the two regions were separate basins at least during the latter part of the Permian, and were separated by a great series of reefs. It is probably this separation which makes paleontological correlation so difficult. At the same time the reefs have obscured the field and subsurface relationships, placing formations of different ages in seeming stratigraphic continuity. It is hoped that with the evidence now at hand an approximation to the truth may be reached, and the opposed lines of evidence somewhat reconciled.

[1]Personal communication.

GLASS MOUNTAINS SECTION

The section of Permian rocks exposed in the Glass Mountains northwest of Marathon has been well described by several writers. The latest work done in this region is by Keyte,[1] Blanchard, and Baldwin [2] and by the King brothers.[3]

This series is divided into the following formations.

Bissett
Tessey
Gilliam
Vidrio
Word
Leonard
Hess
Wolfcamp
Upper Gaptank

The lowermost formation which may include Permian beds is the upper Gaptank. Keyte identifies this as a transitional formation between the Pennsylvanian and the Permian. It is probably upper Cisco and possibly in part lower Albany in age. Above it lies the Wolfcamp, a formation of yellow shale and hard gray limestone which is definitely lower Permian.

The Hess formation is predominantly limestone. The King brothers distinguish eastern and western facies. The eastern is thin-bedded. The western is massive light gray non-dolomitic limestone. The formation carries many beds of limestone conglomerate.

The Leonard and Word formations resemble each other in character. They consist of black limestone and yellow shale and sandstone. Each has a northeastern and a southwestern facies. The southwestern facies of the Leonard consists mostly of brown siliceous shale with thin beds of limestone. The eastern facies consists mostly of limestone with comparatively small amounts of shale. The whole grades eastward into dolomite.

The Word carries more sandstone than the Leonard, but shows the same gradation eastward into dolomite and limestone.

[1] I. A. Keyte, "Correlation of Pennsylvanian-Permian of Glass Mountains and Delaware Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929).

[2] I. A. Keyte, W. G. Blanchard, Jr., and H. L. Baldwin, Jr., "The Gaptank-Wolfcamp Problem of the Glass Mountains," *Jour. Paleont.*, Vol. 1 (1927), p. 175.

[3] P. B. and R. E. King, "Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Univ. of Texas Bull. 2801* (1928), pp. 109-45; "Stratigraphy of Outcropping Carboniferous and Permian Rocks of Trans-Pecos Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929).

The Vidrio, Gilliam, and Tessey formations are predominantly limestone and dolomite. They are similar to the Capitan limestone, the Queen sand series, and the Carlsbad limestone of the Guadalupe Mountains. The Vidrio is the most massive of the three. The Gilliam carries considerable sand, which increases greatly to the northeast. It should be observed that this gradation is in the opposite direction from that found in the Leonard and Word.

Overlying the Tessey unconformably is the Bissett formation, a series of red beds and conglomerate. This series is thought by the King brothers, who named the formation,[1] to be Permian.

The uplift which accompanied the folding of the Marathon region prior to the deposition of the upper Gaptank formation established a land mass southeast of the Glass Mountains which must have persisted until the end of Word time at least, and reappeared during Bissett time, if it did not remain throughout the Permian. The numerous conglomerates in the Hess indicate its proximity. The shales and sands of the Leonard and Word were derived from it, and from its westward extension. The successive overlap of the formations from the Gaptank to the Word is additional evidence of the proximity of this land mass. Southwestward along the southeastern front of the Glass Mountains, each succeeding formation overlaps the one below it and rests directly on the folded Pennsylvanian beds.

OTHER TRANS-PECOS TEXAS SECTIONS

Various Permian formations are exposed in the region between El Paso and Pecos River. They include practically a complete section of the Permian. The formations exposed are as follows.

Upper Red-beds	
Rustler dolomite	
Castile gypsum	
Apache limestone	
Frijole limestone	Delaware Mountain formation
Delaware Mountain sandstone	
Bone Springs limestone	
(Leonard)	
Permian limestone of Hueco series	

Keyte states that the lowermost part of the Hueco limestone series is pre-Permian. The uppermost beds of the series may be as young as Word. It certainly includes Leonard, though it cannot be accurately defined. In the Sierra Diablo the Leonard can be differentiated on lith-

[1] P. B. and R. E. King, "Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Univ. of Texas Bull. 2801* (1928), p. 140.

ologic and faunal evidence. It is the same as the Bone Springs limestone member of the Delaware Mountain formation farther northeast.

The Delaware Mountain formation, as first described, included both the great thickness of sandstone (Fig. 6) found in the Delaware Mountains, and the black and gray limestone series found below it in Bone Springs Canyon (Fig. 5) near the southern end of the Guadalupe Mountains. The uppermost member of the formation is a black limestone approximately 40 feet thick. This can be recognized in the subsurface and makes a good structural marker. It has commonly been referred to by the workers in this region as the Frijole limestone, because it was thought that the black limestone of similar character which outcrops at Frijole post office was at the top of the sandstone section. This is not the case, though this limestone does lie at the top of the section at Guadalupe Point, where the upper part of the sandstone has graded northwest into dolomite. For this reason the name Upper dark limestone is used here in preference to the name Frijole limestone.

The Delaware Mountain sandstone does not seem to be related to any of the clastic sediments of the eastern New Mexico and western Texas Permian. It is exceedingly fine-grained and uniform in character throughout its whole extent. It carries marine fossils, and is known to extend only a short distance northwest of the Guadalupian barrier. It probably had its source in the land masses farther southwest, between El Paso and the Marathon uplift, whereas the sediments of the basin on the north came from lands on the northwest, north, and east.

The Delaware Mountain sandstone, and possibly the Upper dark limestone, produce high-gravity non-sulphurous oil in the Porterville pool in Loving County. Many showings have been found in it, but as yet no well closed structure has been drilled in the area underlain by it. Should such a structure be found, the Delaware Mountain sandstone may prove a most prolific reservoir.

The Apache limestone is found in the Apache Mountains northeast of Van Horn. It is described by Crandall[1] as a reef or series of reefs. It belongs to the great system of reefs which formed the Guadalupian barriers. These will be discussed more fully later.

The Castile gypsum (Fig. 7) overlies the Frijole limestone both on the outcrop and in the subsurface throughout the area underlain by the Delaware Mountain sandstone. No evidence of an unconformity ex-

[1]K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929).

ists, but there must have been a radical change in conditions of deposition, some barrier forming on the west to close off the formerly marine Delaware Mountain basin from the open sea. The Castile may be divided, in the subsurface, into upper and lower sections. The lower section is banded anhydrite, carrying a little dolomite, and two or more beds of white salt which aggregate approximately 600 feet in thickness. These can be used to some extent as structural markers. The upper Castile includes the main salt series in the eastern part of the basin, reaching its maximum thickness of 2,400 feet in south-central Lea County. Westward this salt series grades into anhydrite, and probably outcrops as gypsum.

The Castile gypsum is overlain by the Rustler dolomite (Fig. 7) which outcrops in the Rustler Hills west of Pecos River and which can be traced in the subsurface throughout a large part of the Permian basin. Southward toward the Glass Mountains the upper part of the Castile becomes more dolomitic. This fact suggests that the Tessey, the uppermost formation of the dolomite series of the Glass Mountains, may include beds as young as the Castile and the Rustler.

The Rustler is overlain by the Red-beds (Fig. 8) which outcrop along Pecos River. These are the youngest Permian beds of this region, and are correlated with the Quartermaster of Oklahoma.

After extensive and detailed paleontological study of the Permian of trans-Pecos Texas, Keyte[1] makes the following correlations. The Permian limestone of the Hueco Mountains is equivalent to the upper Gaptank, Wolfcamp, Hess, and Leonard, and possibly part of the Word. The Delaware Mountain formation is equivalent to the Leonard and the Word, the Bone Springs member to the former, and the sandstone to the latter. It should be stated that as shown on Keyte's chart this is the part of the Delaware Mountain formation below the Capitan. The upper part of the Delaware Mountain sandstone, which grades into the lower Capitan, is probably equivalent to the Vidrio, and the upper black limestone may correlate with the Gilliam and part of the Tessey.

THE GUADALUPIAN BARRIERS

THE GUADALUPE MOUNTAINS

Several papers have recently been published or are now in press, which throw light on the obscure problems of stratigraphy and correla-

[1] I. A. Keyte, "Correlation of Pennsylvanian-Permian of Glass Mountains and Delaware Mountains, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929).

tions of the Guadalupe Mountains.[1] Some points, however, still remain to be clarified.

The principal contribution has been the recognition of the Capitan limestone as a reef and the clarification of the conditions of sedimentation which must have gone hand in hand with its development.

From a study of the various classifications, the following divisions may be recognized in the section from Guadalupe Point, at the south end of the mountains, to Carlsbad, the part of the mountains in which is found the typical Guadalupian series.

Carlsbad limestone Queen sand series Lower Capitan limestone	Capitan limestone
Delaware Mountain sandstone Bone Springs limestone	Delaware Mountain formation

The Bone Springs limestone is a black and gray thin-bedded limestone, which locally shows steep depositional dips or cross-bedding. It is the oldest formation exposed in the Guadalupe Mountains.

The Delaware Mountain sandstone rests unconformably on the Bone Springs. The latter rises toward Guadalupe Point from the east and southeast in an old topographic scarp, the southeastern edges of the beds having been eroded away. The sandstone was deposited against these edges. The bedding in the two series is practically parallel, hence a thick section of Delaware Mountain sandstone is cut out by the Bone Springs. A section of 2,700 feet of sandstone can be measured on the southeast, but over the Bone Springs at Guadalupe Point only 200-300 feet are present.

Over the Delaware Mountain sandstone at Guadalupe Point, there is a bed of black limestone similar to the upper black limestone between the sandstone and the Castile gypsum farther south. This is actually about 700 feet below the upper black limestone. This is the bed which outcrops at Frijole. It is of importance as marking the base of the Capitan limestone, but it is not the top of the Delaware Mountain formation.

Above the Delaware Mountain at Guadalupe Point lies the Capitan limestone (Figs. 6 and 7). This forms a cliff 1,800 feet high. On the

[1] E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929). K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929). W. G. Blanchard, Jr., and Morgan J. Davis, "Permian Stratography and Structure of Parts of Southeastern New Mexico and Southwestern Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929).

northeast it forms the scarp of the eastern spur of the mountains. It is fully described in the papers by Blanchard and Davis, Lloyd, and Crandall, previously cited. This limestone represents an immense fossil reef. The seaward side of this reef was on the southeast.

Northwest of the Capitan limestone the formations equivalent to it are the San Andres, the Queen sand series, and the Carlsbad limestone (Fig. 6). The San Andres limestone has already been described. In this area it has a thickness of 1,000 to 1,100 feet. The Queen sand series is similar to the San Andres in character, but carries a large amount of sandstone interbedded with the limestone. Blanchard and Davis regard it as an upper member of the San Andres, but the writer believes that it should be separated, for reasons which will appear shortly.

The Carlsbad limestone overlies the Queen series. It is made up of thin-bedded limestones, and shows strong depositional dips. It is the lagoonal facies of the upper part of the Capitan reef.

CORRELATION OF THE GUADALUPIAN SECTION

Correlation of the beds of the Guadalupe Mountains with those of the trans-Pecos Texas basin on the south and with those of east-central New Mexico on the north should give us the final link in our understanding of the Permian of this region.

The Bone Springs limestone probably grades north into the lower Yeso. There is disagreement on this point, some workers being inclined to put it in the Abo, but Morgan Davis[1] believes he has found sections intermediate between the two. The first of the Guadalupian barriers is thought to have formed in Bone Springs time. The twin "arches" at Bone Springs Canyon and Tank Canyon on the west face of the Guadalupe Mountains first shut off the sea from the area northwest and permitted the development of salt-basin conditions in the Yeso. These barriers have generally been considered as due to uplift and erosion, resulting in the unconformity between the Bone Springs and the Delaware Mountain sandstone. The parallelism of the beds of the two formations at Bone Springs leads the writer to doubt this explanation. Though these barriers are now located on anticlinal folds, these folds are reflected in all of the Permian beds, and are thought to be much younger, possibly Laramide, in age. E. Russell Lloyd[2] suggests that the Bone Springs limestone may also be a reef, and that there may be no actual unconformity between it and the Delaware Mountain sandstone, the latter grading

[1] Morgan J. Davis, personal communication.

[2] E. Russell Lloyd, *op. cit.*

northwestward into the former. The writer believes that this unconformity actually is present, and that erosion of the Bone Springs has taken place, but it is possible that a reef face lay southeast of the present remnant, where the cross-bedded limestone suggests current deposition and possibly lagoonal conditions. Erosion may have removed the reef facies, and the Delaware Mountain sandstone may have been laid down against the slope of the remaining beds, after a very short time interval compared with that necessary for folding, uplift and subsequent erosion. This explanation gives us a barrier during as well as after Bone Springs time, making it possible to explain the salt-basin conditions in the lower Yeso during Bone Springs time.

In discussing this unconformity it should be noticed that if both the Bone Springs and the Delaware Mountain sandstone are correlated with the Yeso, the time of the unconformity falls in the middle Yeso. If the correlation is carried around the Panhandle, this is found to approximate the position of the unconformity at the base of the San Angelo, a fact that may be significant.

The thin remnant of Delaware Mountain sandstone between the Bone Springs and the Capitan at Guadalupe Point thickens northward as it does southward. It can be followed for a considerable distance along the west front of the Guadalupe Mountains. At its northernmost exposure it has many characteristics of the Yeso. Farther north the Yeso is found directly under the San Andres (the Glorieta having pinched out farther north) in the same position occupied by the Delaware Mountain sandstone under the Capitan. The San Andres is traceable directly into the lower Capitan; hence it is logical to correlate the Delaware Mountain sandstone (or that part of it below the lowermost Capitan) with the upper Yeso.

The chief disagreement between the paleontologists and the men who have studied the Guadalupian Permian in the field is on the subject of the correlation between the San Andres and the Capitan. The San Andres fauna is an older and less developed fauna than the so-called Guadalupian fauna. The same objection has been raised to the correlation of the San Andres and the Blaine. The field relationships, however, indicate that the San Andres is equivalent to the lower Capitan. Blanchard and Davis have traced the San Andres limestone and the Queen sand series south to a point where the former carries masses of reef limestone, and where it overlies typical Delaware Mountain sandstone. At this point it occupies the same stratigraphic position as that occupied by the Capitan on the southeast. If it were not for the reef masses within it

there might still be some doubt. Crandall[1] describes the relation between the Capitan and the Chupadera beds, which he states may include parts of the Yeso and San Andres. He states that these beds occur as a thin section below the Capitan limestone near the Guadalupe Point, and that northward they thicken and the Capitan thins above them, until they occupy the position held farther south by the Capitan. Quoting him: "Whether the contact of this series with the Capitan is conformable is not known, but it is very evident that it is comparatively older than the true massive Capitan." The writer does not believe that this is necessarily so. Crandall states that the contact is obscure, hence it may well be one of intergradation, as indicated by the reef masses found by Blanchard and Davis in the San Andres. Southeast of the Capitan the upper 700 feet of the Delaware Mountain sandstone grades into the lower Capitan, yet farther northwest undoubted San Andres overlies typical Delaware Mountain sandstone. The upper part of the massive Capitan is equivalent to beds younger than the San Andres (the Queen series and the Carlsbad) but it seems reasonable to correlate the San Andres with the lower Capitan.

Though the limestone of the Queen sand series has characteristics similar to those of the San Andres, the writer believes it should be separated because it appears to grade northward into the lower part of the Seven Rivers and associated gypsum formations, and in the subsurface into the lower or sandy part of the anhydrite series in the Artesia district. The San Andres retains its marine facies far north and northwest of this point; in fact it is described in the San Andres Mountains and traced east and south to the Guadalupe region. If the Queen series does not have the characteristics of the San Andres in the type locality of the latter, it should not be included in the formation even where it assumes those characteristics.

The top of the Queen series in the subsurface is generally thought to be the red sand already mentioned as a marker in the Artesia and Maljamar districts. The top of the Carlsbad can be traced eastward in the subsurface under the main salt. The correlation shown on the accompanying chart indicates that the combined Queen and Carlsbad formations are equivalent to the Whitehorse. By the correlation suggested by DeFord the Queen series alone would be Whitehorse, and the Carlsbad would be Cloud Chief in age.

The relation of the Queen series and the Carlsbad to the Seven Rivers gypsum has been the subject of considerable discussion. The

[1]K. H. Crandall, *op. cit.*

gypsum formation appears to be a wedge from the west lying between the Queen series below it and the Carlsbad which overlaps it. The uppermost Carlsbad can be seen grading into gypsum, and the Queen series also probably grades northward into gypsum, so though it is possible locally to distinguish the different ages of the Seven Rivers, the Queen, and the Carlsbad, the three together represent the same time interval as the uninterrupted reef-building of the upper Capitan, and the Carlsbad and Queen may be considered for purposes of regional study equivalent to the Seven Rivers and its associated gypsum formations. In the subsurface the limestone and sand sections of the Queen and Carlsbad seem to grade directly into the anhydrite and sand section, and it is impossible to recognize the local unconformity under the Carlsbad.

On the southeast flank of the Guadalupe Mountains the upper 700 feet of the Delaware Mountain sandstone can be seen grading northwest into massive Capitan limestone. Beede correlates the Word with the Blaine on paleontological evidence. The chain can be carried through, by disregarding the paleontological correlation of the San Andres, as follows. The Word is equivalent to the Delaware Mountain sandstone, the upper part of which grades into the lower Capitan. This grades into the San Andres which is equivalent to the Blaine. This is the only good paleontological tie that can be made between the trans-Pecos and the Texas basins, but it serves as a starting point for the correlation of the rest of the formations.

Crandall shows that the Upper dark limestone, which caps the Delaware Mountain formation, rises abruptly to the northwest into the Capitan scarp, and seems to be equivalent to the youngest part of the Capitan limestone. It may, therefore, be as young as the Carlsbad limestone, which would give an age range for the whole Delaware Mountain formation from early or middle Yeso through Carlsbad, or from Clear Fork through Whitehorse time. If only the lower 700 feet of Capitan is equivalent to the upper Delaware Mountain sandstone, the Upper dark limestone may represent a long time interval, and be equivalent to both the Queen series and the Carlsbad.

The Castile gypsum is believed by Lloyd and Crandall to be younger as a whole than the Carlsbad. It seems unlikely that reef-building organisms could have lived in a sea of sufficient salinity to precipitate the Castile. Blanchard and Davis believe that the lower Castile may be in part equivalent to the Carlsbad, arguing that fresh waters may have come into the basin and followed the line of the reef, and that algae are found actually building reefs in waters which are at the same time de-

positing anhydrite. In either case the field relations show that the main body of the Castile is younger than the Carlsbad, and therefore latest Whitehorse and Cloud Chief in age. The correlation of the Rustler with the Cloud Chief has already been discussed, as has that of the upper Red-beds with the Quartermaster.

SUBSURFACE SECTION OF THE WINKLER AND LEA COUNTY "HIGH"

This section differs from the section of the main basin northeast of it in that the top of the lime occurs a very short distance below the base of the salt. This interval ranges from 50 to 150 feet on the "high," whereas on the east there is from 900 to 2,000 feet of anhydrite between the salt and the San Andres-Blaine limestone. The sequence on top of the "high" is seemingly identical with that farther east. Porous white dolomite grades upward into anhydrite. There is some sand in the white dolomite in places, but there is also some sand in the upper part of the San Andres. Even the green bentonite occurs on the "high" at about the same distance below the top of the white lime as it does farther east. The duplication of the sequence between these two areas is so perfect that the writer for a long time considered the Winkler County "high" as a great structural feature with the anhydrite section thinning out almost to nothing on top of it. Wells drilled in the southeastern part of Lea County along the eastern edge of this "high" now indicate that it is only in part a structural feature, and that the upper dolomite on the "high" grades into anhydrite and sand toward the east. Along the eastern edge of the "high," wells which found the top of the lime a relatively short distance below the salt drilled a thick sand section unlike any section of the San Andres or Blaine limestone farther east. The sand horizons of this section correlate with the sand horizons of the anhydrite series farther east. The more prominent beds carry gas and can be correlated with the red sand marker already mentioned as the top of the Queen sand series and with other sand lenses below it which carry showings of oil and gas in the Maljamar district. These horizons are possibly the same as the producing horizons in the Red-beds in the Chalk and Clay pools in Howard County. Six or seven bentonite horizons, ordinarily red but in places green even in the anhydrite series, can be recognized between the true San Andres and the base of the salt.

Eastward from the outcrop of the Carlsbad limestone, the section under the Getty pool is identical with that in Winkler County. Porosity conditions are also similar to those in Winkler County. In the Winkler County pool the porous horizons are practically continuous vertically in the western part of the pool, but in a short distance east-

ward the section becomes less porous. West of the Winkler County pool, wells have been drilled with a great thickness of anhydrite below the salt. These pass directly into the Delaware Mountain formation without encountering the "Big lime" section. These facts show that the reef of Capitan and Carlsbad age extends around the Eddy County and western Lea County basin (Figs. 5 and 6) to the Hendricks pool, and that the gradation of the upper or Carlsbad and Queen part of this reef eastward into the anhydrite series corresponds with the gradation found on the surface of the Queen sand series and possibly of the Carlsbad northward into the Seven Rivers and associated gypsum beds.

An interesting stratigraphic gradation in the upper part of the section occurs over the Winkler County high. The salt series which is continuous over the whole area thins decidedly and changes to anhydrite over the line of the reef. This is true from the north end of the Winkler County pool to a point south of Pecos River in Pecos County. The thinning is not greatest over the present high points of the structure, but rather over the line of the reef itself which is west of the anticline. It is impossible to interpret this gradation into anhydrite as a gradation toward marine conditions, as the anhydrite grades into salt both toward the east and toward the west. This stratigraphic anomaly is probably due to localization of currents over the reef. It has a counterpart in the gradation of the Cloud Chief gypsum into the Alibates dolomite on the top of the Panhandle arch.

SUBSURFACE SECTION OF THE FORT STOCKTON "HIGH" AND THE YATES POOL

The line of the Winkler County "high" can be projected south to the Fort Stockton "high" and from there it can be traced eastward to the Yates pool in Pecos County. A difference is observed, however, between the Fort Stockton "high" and the Winkler County "high." In the latter the section west of the "high" is typical of the Delaware Mountain basin; in the former, the section west of the "high" seems to be identical with that east of the "high" in the McCamey district.

The Fort Stockton and Yates "high" (Fig. 6) shows several features which strongly suggest that it is a reef. Great thicknesses of limestone have been drilled, and these have been found to be porous throughout. This porosity decreases in a short distance northeast. No clastic sediments have been found below the top of the lime on the "high" itself. This is also true of the reef under the Winkler County "high" even in that section which correlates with the Queen sand series. Toward the west and south from McCamey the top of the lime appears to rise in

the section. This peculiar condition was thought at first to be a gradation toward the section of the Glass Mountains which is all dolomite, but when the section west of the "high" near Fort Stockton was examined, this possibility was precluded. The writer believes that the top of the lime of the Fort Stockton "high" from a point just south of Pecos River to the Yates pool represents a reef the youngest beds of which are intermediate in age between the Blaine-San Andres and the youngest beds of the Carlsbad formation. South of the Fort Stockton "high," the anhydrite series below the salt carries red beds throughout its section, whereas north of the "high" the red beds are confined to the upper part of the anhydrite section. Wells which penetrated the lime south of the "high," in particular the Phillips Hyman, drilled a thick sand section below the top of the lime. It is thought that this section corresponds approximately with the Queen sand series or lower Whitehorse and that the anhydrite and red-bed section above corresponds with the Carlsbad or upper Whitehorse. It is thought that the locus of reef-building shifted from the Fort Stockton "high" to a line between the Glass Mountains and the northern corner of Pecos County (Fig. 6) at the end of Queen time, thus permitting the deposition of anhydrite east of the younger reef and on the southern (marine) side of the older reef.

Carrying this correlation eastward one would expect to find the same gradation of the lower part of the anhydrite series into lime toward the southeast from McCamey to the Yates pool. This would make the Yates "pay" younger than the McCamey and Church and Fields "pays."

In the area between the Fort Stockton "high," McCamey, and Yates, the salt grades into anhydrite toward the south and west just as it does over the Winkler County reef. But it seems to grade back into salt south of the Fort Stockton "high." The writer believes that in the Yates pool some of the anhydrite section is actually of salt age, rather than that the salt pinches out throughout the field.

CORRELATION OF THE GLASS MOUNTAIN SECTION

In the foregoing correlations, the areal extent of the clastic sediments has been used, as well as continuity of the chemical sediments. Extending the correlations southwest to the Glass Mountains, it seems likely that the relatively non-clastic San Andres-Blaine series is represented there by the non-clastic Vidrio, and by the Leonard and Word, the clastics of which came from the south, that the clastic Whitehorse-Queen sand series is the equivalent of the Gilliam, which grades to sand northeastward toward the area of Whitehorse deposition and which cor-

responds with the sandy phase of the "Big lime" section found south of the Fort Stockton "high," and finally that the Tessey is the equivalent of the Carlsbad, the Castile, and the Rustler.

SUMMARY OF PERMIAN HISTORY

The stratigraphic gradations and correlations outlined in this paper may be summarized in the following history of the Permian basin.

During Wichita-Albany time the land masses were restricted in extent and confined to the persistent positive areas of the Wichita Mountains, the Pedernal Hills and their connecting link, the Panhandle arch. The Central Mineral region, if not submerged, was at least low-lying and unimportant as a source of sediments. Marine conditions extended in early Wichita-Albany time across the Panhandle arch, but receded in the latter part of this period south of the arch and west of the present outcrop of these formations, leaving the Wellington salt basin in Kansas and western Oklahoma. The open sea lay toward the southwest. A land mass existed in the Marathon region, but the sediments supplied by it were local.

During Clear Fork time the uplift in the region between the Wichita Mountains and the Llano-Burnet region caused a wider distribution and a change in the character of the clastic sediments. A corresponding uplift in northern New Mexico and the formation of a barrier along the southeast front of the Guadalupe Mountains caused the change from the Abo to the Yeso type of deposition.

A marked uplift in the Llano-Burnet region caused an unconformity at the end of Clear Fork time and furnished the sediments for the deposition of the San Angelo-Duncan series. Marine conditions still existed through most of the southern part of the Permian basin, but the salt deposits of the Clear Fork in the Panhandle region were continued. The uplift toward the southeast has its counterpart in the southern Rocky Mountain region, which furnished the widespread sands of the Glorieta formation. Deposition of the Delaware Mountain sandstone began during this time.

The period of uplift marked by the San Angelo and Glorieta was followed by a period in which the chemical sediments became more widespread. The first positive evidence of reef-forming is also found at this time. A semicircle of reefs was built around the southwestern part of the basin from Guadalupe Point to the Yates pool. Within this line of reefs Delaware Mountain sandstone deposition continued, but back of it, throughout eastern New Mexico and in the southern part of the

West Texas basin, limestones were formed in a restricted sea. These include the San Andres limestone of New Mexico, which grades northward and eastward into the Blaine of Texas and Oklahoma. During this time salt deposition was extended southward as shown by the salt deposits of Blaine age in the basin just south of the Panhandle. These extended as far southwest as Roosevelt County, New Mexico.

The San Andres-Blaine period of quiescence and of restricted clastic sediments was followed by uplifts throughout the area from the Wichita Mountains to the Central Mineral region and possibly southwest to the Marathon region and beyond. This uplift furnished the widespread clastic sediments of Whitehorse time. Delaware Mountain deposition probably continued into this period without interruption. The barrier reef persisted, but, due either to the influence of clastic sediments or to some climatic change, the waters back of the barrier became more saline, anhydrite and salt being deposited in place of limestone and dolomite. Toward the end of this time, the southeastern part of the reef between Fort Stockton and the Yates pool was replaced by a reef farther west which connected the Glass Mountains directly with the old reef in Ward County.

The final stage in the cutting off of the West Texas basin from the sea was reached during Cloud Chief time, when a barrier separated the Delaware Mountain basin from the sea on the west. This permitted (1) the deposition of the Castile formation, and (2) the extraordinarily widespread and uniform deposition of the big salt series which extended without a break from Reeves and western Pecos counties north nearly to the Panhandle.

Deposition of the salt was followed by one more freshening of the waters of the whole area, which permitted deposition of the Rustler dolomite in the southwest and of the Cloud Chief gypsum and Alibates dolomite in the northeast. This was followed by uplift of all the land masses around the Permian basin, from which the sands and shales of the Quartermaster formation were spread over the whole area formerly occupied by the Permian sea.

SUMMARY OF OIL-PRODUCING FORMATIONS

All of the formations of the Permian up to and including the Carlsbad limestone produce oil in some part of the Permian basin.

The Wichita-Albany series produces oil in the Panhandle. This production is restricted to the lower part of the formation. Though porous horizons have been found in this same zone wherever the Wichita-Albany has been encountered south of the Panhandle, no commercial production has been found in them.

The Clear Fork produces oil from its upper portion in the Westbrook pool, and showings have been found in it in the small producing wells of the districts in Mitchell and Scurry counties. The San Angelo formation also produces oil in this same general area.

The Blaine-San Andres series produces from horizons ranging throughout its section, in the McCamey, Church and Fields, Howard County, Westbrook, Artesia, and Maljamar fields, and from numerous wells in areas not yet developed. Conditions seem to have favored both development of source beds and accumulation over a wide area during this time. The northward limit of Blaine production is probably defined by its gradation into anhydrite and finally into salt north of Garza County.

The Delaware Mountain formation, which is in part at least equivalent to the San Andres, is productive in one small pool and carries good oil showings nearly everywhere. No major field has been developed in it as yet, due to lack of suitable structural conditions.

The Whitehorse and its equivalents furnish various types of production in different areas. The Red-beds of Howard County furnish sweet oil. The producing horizons of the Scarborough pool in Winkler County and of the Hayzlett pool in Ward County are of approximately the same age. Lime production from the Yates pool in Pecos County is thought to be lower Whitehorse in age, and similar production in the Hendricks pool in Winkler County is Carlsbad or upper Whitehorse in age.

The younger formations of the Permian show salt-basin conditions throughout the area where they are now present and oil can not, therefore, be expected from them.

DISCUSSION

ROY H. HALL, Wichita, Kansas: You mentioned in your paper the possible control of reef-building by barriers which were probably pre-reef structure. In this connection I wish to point out the probable control over the deposition of the Capitan and Carlsbad formations (reefs?) by the Bone Springs arch (pre-Delaware fold) as shown by Blanchard. There also seems to be some connection between pre-Delaware folding and the Winkler reef, if it may be called a reef. Blanchard shows a decided thinning of Delaware sands over the "Big lime" under Winkler County oil field. From Blanchard's section there seems to be an analogous history, that is, pre-Delaware folding forming a barrier on or near which a reef was built. I am inclined to the theory that pre-Delaware folding has exercised considerable control over Delaware sedimentation in the Permian basin and that movements along these lines of folding continued to control sedimentation in this area. The time of pre-Delaware folding as illustrated on the west face of the Guadalupe Mountains and as shown by Blanchard, is post-"Bone Springs" or post-lower, perhaps middle Leonard time.

RONALD K. DEFORD, Roswell, New Mexico: I do not believe the so-called Bone Springs "arch" is an arch at all, but is a homocline. I do not believe it was a barrier to the Delaware sea. I think the changes which take place are lateral and the black limestones of the Yeso interbedded with gypsums grade laterally into the Bone Springs or Leonard.

ROY H. HALL: Blanchard shows on his north-south section a steep northwest dip or face to the Leonard fold at Tank Canyon. The gypsums and interbedded black limestones of the lower part of the Yeso terminate against this face or dip slope of the Leonard. On the south between Tank Canyon and Bone Springs there seems to have been both sandstone and gypsum (Delaware) laid down in a shallow trough. However, south of Bone Springs the Delaware deposition is entirely marine. The Bone Springs and Tank Canyon folds are about 12 miles apart. I believe they are pre-Delaware in age of folding and have a northeast strike. These folds were of sufficient size to form a barrier to complete marine deposition on the north side. No doubt the sea breaking over or perhaps connecting with the landward basin or lagoon through narrow chanels supplied salines from which the Yeso gypsums were deposited. Likewise oscillations or perhaps subsidence of the basin southeast may have permitted short periods of limestone deposition on the landward side of the barrier as well as on the seaward side. There seems to be good evidence for at least a part of the Yeso being deposited at the same time as the Delaware formation, separated by a barrier of Leonard limestone. This, I believe, is further proof of pre-Delaware folding controlling deposition of the overlying formations.

STRUCTURAL DEVELOPMENT AND OIL ACCUMULATION IN TEXAS PERMIAN[1]

ROBIN WILLIS[2]
Midland, Texas

ABSTRACT

Regional structure in the Permian basin is due to the sinking of basins around positive elements. In the south the sinking was combined with uplift along the Marathon fold. These structures have been modified by post-Cretaceous deformation in the mountain areas. This is of the Basin Range or block-faulting type.

The limestone "highs" within the Permian basin are in part depositional and in part structural. The Getty "high" is a reef overlain by a typical compaction fold. The Winkler County "high" is a combination of a reef with a deformational "high." The varying relations of these two factors determine the character of production encountered from Winkler County north into Lea County. The Yates "high" is thought to be depositional whereas the Big Lake "high" is thought to be structural. The evidence for and against these conclusions is analyzed.

The final determination of the character of each limestone "high" in the basin is to be found in the structure of the beds below the "Big lime."

INTRODUCTION

There are three factors which must be considered in studying structural development of the Permian of West Texas and southeastern New Mexico. These are: (1) regional structure due to sinking of basins around positive elements; (2) local structure due to deformation; and (3) structure due to deposition. Oil accumulation depends upon the relation of these three factors to one another and to porosity.

It is not possible to evaluate the importance of these factors in all of the producing fields of the Permian, but in certain cases sufficient information is at hand to permit the tracing of the structural history with a fair degree of certainty. It is the writer's purpose in this paper to describe these cases and point out the application of the evidence they present to the study of the other structures of the region.

STRUCTURAL FEATURES OF THE BASIN

The broader structural features of the Permian basin in West Texas and southeastern New Mexico include two principal basins divided by a

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, June 4, 1929.

[2]Consulting geologist, Box 1405.

double line of "highs." The basin east and north of these "highs" may be termed the main West Texas basin; that west of them, the Delaware Mountain basin (Fig. 1). The two more or less parallel "highs" between them are the "high" of Crane, Upton, and Ector counties, on the northeast, and that of Ward, Winkler, and Lea counties. In addition to these there are the following limestone "highs" in the basin: the Garza County "high," the "high" of Howard and Mitchell counties, the Big Lake and World-Powell "high," the Apache Mountain "high," and the Getty

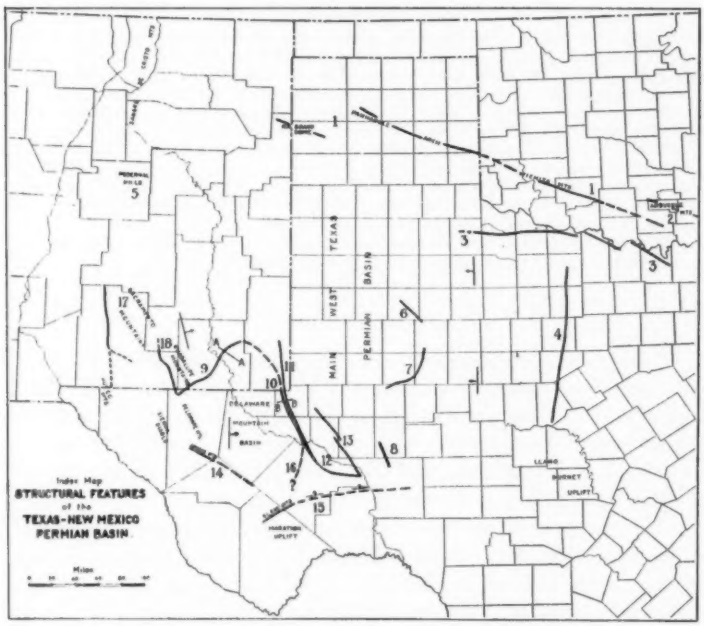


FIG. 1.—Limestone "highs" of West Texas and southeastern New Mexico and their relation to structural trends in the surrounding regions. *1*, Panhandle arch and Wichita positive element. *2*, Arbuckle Mountain zone of compression. *3*, Red River arch. *4*, Bend arch. *5*, Pedernal positive element. *6*, Garza County limestone "high." *7*, Howard and Mitchell county limestone "high." *8*, Big Lake and World-Powell limestone "high." *9*, Capitan reef and the Getty "high." *10*, Line of Capitan reef in Lea and Winkler counties. *11*, Structural "high" in Lea and Winkler counties. *12*, Fort Stockton-Yates limestone "high." *13*, Crane-Upton limestone "high." *14*, Apache Mountain reef and Davis Mountain fault. *15*, Marathon uplift and southern margin of Permian "Big lime." *16*, Possible southern extension of Winkler County reef. *17*, Sacramento Mountain uplift. *18*, Guadalupe Mountain uplift. The cross sections shown in Figures 2 and 3 are indicated at *AA* and *BB*.

"high" in Eddy County, New Mexico. These "highs" are mapped on the top of the "Big lime," and most of them are reflected in the beds above the lime.

The questions that arise in regard to the limestone "highs" are: (1) how was the limestone structure itself formed; (2) how was the structure in the beds above the lime formed; (3) what was the age of deformation, if any has occurred; and (4) what is the structure in the beds below the lime?

DEVELOPMENT OF REGIONAL STRUCTURE

Two distinct periods of deformation may be recognized in the development of the major structural features of this region. The main basins were formed during Permian time, but there was little actual local deformation north of the line of the Marathon uplift. The effects of post-Permian deformation can be recognized in the mountain uplifts of the Davis, Guadalupe, and Sacramento mountains, and of the smaller ranges west of the Pecos. This deformation is probably contemporaneous with the deformation of the Basin ranges of Utah, Nevada, Arizona, and western New Mexico, and is related to the Cordilleran province rather than to the deformational effects found in the Mid-Continent region.

On the east a long monocline extends from the axis of the Bend arch westward to Reagan, Glasscock, Howard, Mitchell, Scurry, and Garza counties. This monocline was formed by the sinking of the main West Texas Permian basin, most of the movement occurring during Double Mountain time. On the north, deposition thinned over the positive element of the Panhandle arch. On the south, the "Big lime" is turned up rather abruptly under the Comanche cover, and it is thought that this represents the eastward extension of the Marathon uplift. This line was not only a positive element, but was repeatedly uplifted from late Pennsylvanian time, when it was strongly folded, until after the close of the Permian. A renewal on the old line of weakness in post-Comanche time is shown by the doming of Comanche beds in the Glass Mountains. The force which caused this latest uplift probably came from a different direction from that which caused the earlier uplifts.

On the west the long monocline of the Delaware Mountain formation is at least in part of Permian age. This is shown by the thickening of the salt eastward. On the north, in the Guadalupe Mountains, the beds west of the subsurface monocline have been tilted toward the east in the Guadalupe Mountain uplift, and those farther north and west have undergone similar deformation in the Sacramento Mountains. These

two uplifts are bounded on the west by faults and sharp flexures, and this deformation is thought to be post-Cretaceous in age.

In the Apache and Davis mountains a long sharp monoclinal flexure and fault forms the northeast face. This can definitely be dated as post-Cretaceous, as beds of that age are involved in the faulting.

CAPITAN REEF SYSTEM

It is now a generally accepted fact that some of the limestone "highs" of the Permian basin are depositional rather than structural. Limestone reefs of great magnitude are found on the surface in the Guadalupe Mountains, the Glass Mountains, and the Apache Mountains. The best known of these is that of the Guadalupe Mountains, the reef limestone itself being designated as the Capitan limestone.[1] This reef can be traced in the subsurface through the Getty pool. Stratigraphic conditions in this pool are duplicated so closely in southeastern Lea County and in Winkler County that there can be little question that the "high" of Winkler and Lea counties is a part of the Guadalupian reef system. We can study the reef structure on the surface, and by analogy determine how much of the Winkler County structure is due to reef building and how much is due to deformation.

The line of the Capitan reef, though a definite limestone "high," must not be confused with the uplift of the Guadalupe Mountains. The former extends northeast. If it is related to any structural feature it was formed on the southeast flank of the Bone Springs-Tank Canyon positive element, but the exact nature of this structure is not known. The Guadalupe Mountain uplift is of the so-called Basin Range type, with a sharp flexure combined with faulting on the west face, and a monoclinal tilting toward the east.

Getty structure.—The Getty pool is shown in cross section in Figure 2 (No. 9 and line *AA*, Fig. 1). It shows the characteristics of a normal reef with no deformation except that due to regional tilting and to compaction. It is similar to the structures found on the west at the surface. Structure mapped on the top of the lime shows an asymmetrical cross section and a very steep dip on the seaward (southeast) side. The structure is rather flat on top and has a comparatively gentle northwest dip.

[1] E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 645-58. K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 927-44. W. G. Blanchard, Jr., and Morgan J. Davis, "Notes on Permian Stratigraphy and Structure of Parts of Southeastern New Mexico and Southwestern Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 957-95.

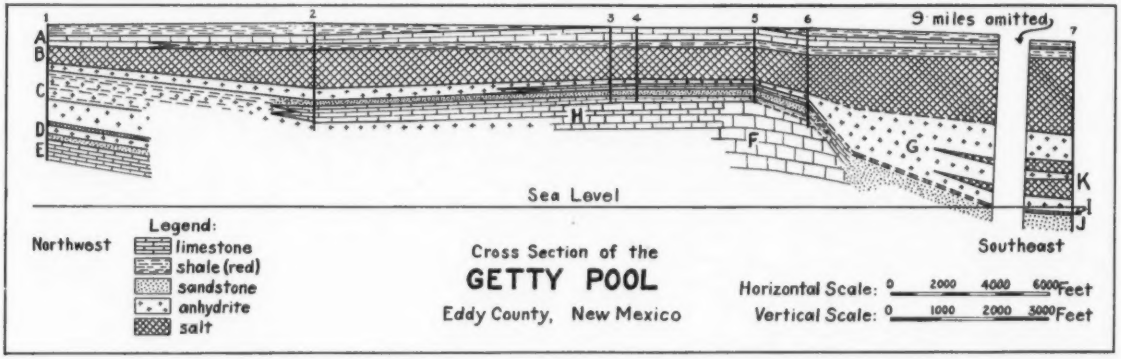


FIG. 2.—Cross section of the Getty pool, Eddy County, New Mexico, a typical depositional "high" overlain by a compaction fold. *A*, Rustler dolomite. *B*, Main salt series. *C*, Seven Rivers gypsum and red shale. *D*, Queen sand series in the lower Seven Rivers. *E*, San Andres limestone. *F*, Depositional "high" of the Capitan reef limestone. *G*, Castile gypsum. *H*, Carlsbad limestone, lagoonal facies of the Capitan. *I*, Upper dark limestone of the Delaware Mountain formation. *J*, Delaware Mountain sandstone. *K*, White salt in the Castile gypsum. Wells shown: *1*, Marland-Hogan, Johnson 1; *2*, Cook Ironsides, Dooley 1; *3*, Getty, Dooley 1; *4*, Getty, Hinckle 1; *5*, Getty, Nicholas 1; *6*, Snowden-McSweeney, Lawrence 1; *7*, Marland, Workman 1.

Toward the northwest the limestone of the upper part of the reef grades into or interfingers with gypsum, anhydrite, and red beds. The limestone of the lower part of the reef grades into the San Andres limestone. Points taken on the top of the first limestone encountered, therefore, show a drop toward the northwest as steep as that toward the southeast, but this is not a true dip. It is merely due to the gradation of the upper limestone into the anhydrite series. Above the limestone the beds thin over the crest of the structure, being thinnest over the highest point in the lime. They reflect the structure in the limestone, however, and the axis in the Rustler at the top of the Permian series is directly over the axis in the lime. This feature may be accounted for entirely by differential deposition and compaction over the topographic elevation of the reef, without recourse to folding.

The Getty structure is apparently a plunging one, but the plunge corresponds with the regional dip of the San Andres and Carlsbad limestones on the surface. This dip is due in part to the sinking of the basin on the east, into which the "high" extends at an angle, and in part to the post-Permian tilting of the Guadalupe Mountain block.

Winkler County structure.—There are at least three distinct fields producing from the lime in Winkler County. They have somewhat different characteristics, but the largest one, the Hendricks pool, shows the same features throughout its length. It differs from the Getty structure, as it is a combination of a depositional "high" and an anticline due to deformation (Fig. 3, and Nos. 10 and 11, Fig. 1).

This "high" shows an asymmetrical cross section similar to that of the Getty pool. The lime, however, does not continue to drop off on the seaward side (in this case toward the west) but the top flattens and it is probable that the reef face is considerably west of the producing arch. As in the case of the Getty pool the beds above the lime thin over the structure but they are thinnest over the western part of the limestone "high" two miles or more west of the axis. The salt series grades laterally from both sides of the "high" into anhydrite and the most anhydrite is found where the series is thinnest. Figure 3 illustrates how the reef was formed and the beds deposited over it, giving the thinnest section over the reef itself. The whole series was then subjected to deformation which produced the Hendricks fold and moved the axis of the limestone "high" toward the east. The thickening of the salt section on the east accounts for the fact that the present axis of the structure in the salt is far east of the axis in the lime.

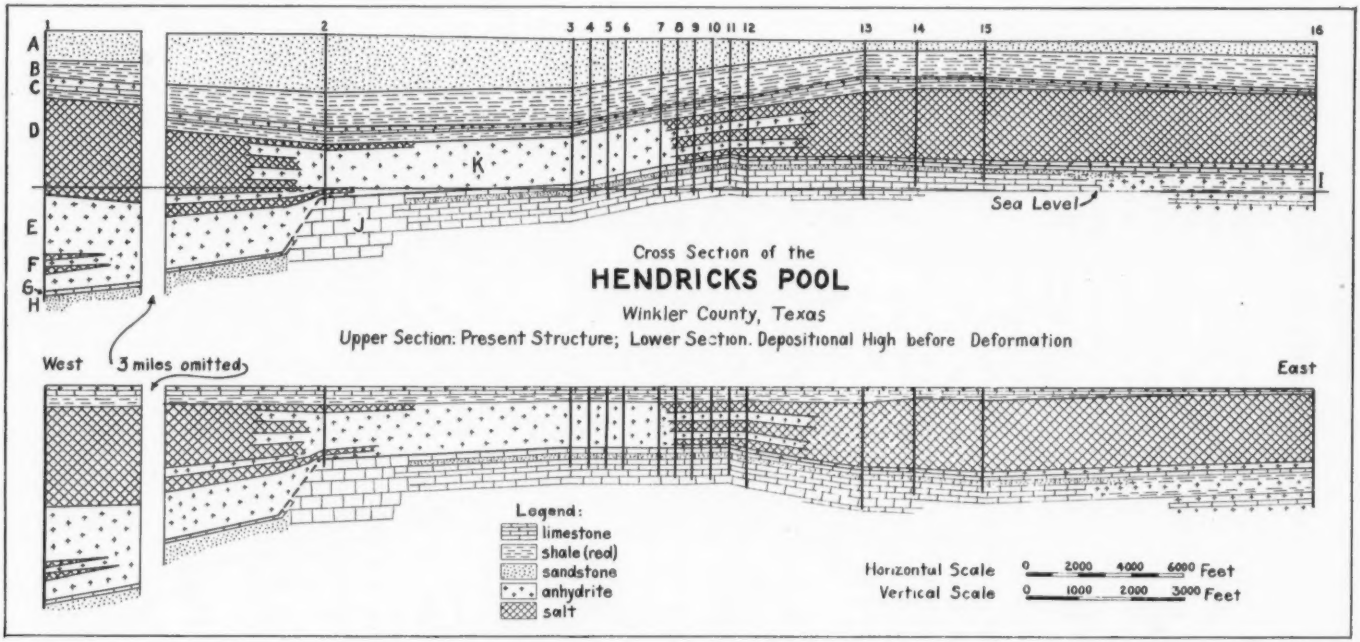


FIG. 3.—Cross sections of the Hendricks pool, showing a "high" due to a combination of deposition and deformation. The upper section represents the present structure; the lower represents the structure as it was before the formation of the syncline west of the pool. This was reconstructed by assuming that the Rustler dolomite was laid down horizontally. It is probable that there was a slight compaction fold in the salt and Rustler formed during and shortly after deposition. This would accentuate the depositional "high." *A*, Triassic and Recent sandstone and shale. *B*, Permian Red-beds. *C*, Rustler series. *D*, Main salt series. *E*, Castile gypsum. *F*, White salt in the Castile. *G*, Upper dark limestone of the Delaware Mountain formation. *H*, Delaware Mountain sandstone. *I*, Anhydrite series east of the "high". *J*, Depositional "high" of the Capitan reef limestone. *K*, Anhydrite replacing salt over the depositional "high." Wells shown: *1*, Skelly, Leeman No. 1; *2*, Humble, Hendricks No. 1; *3* to *12*, wells in the Hendricks pool; *13* and *14*, Independent, McCabe No. 1 and No. 3; *15*, Amerada, Walton No. 1; *16*, Bolin, Brown and Altman No. 1.

The age of deformation seems to be post-Triassic, as the base of the Triassic sands follows the Rustler down into the syncline west of the field. This may be one case in which movement of Cretaceous or later age has modified Permian structure near the center of the basin.

The original structure of the Hendricks pool was probably broader than that of the Getty pool. Farther north in the Leck and Scarborough areas the depositional "high" and the structural "high" can still be distinguished, but the former is narrower and the compaction fold in the salt above the reef still shows reversal toward the east, in spite of the fact that the whole lies on the west flank of the deformational fold.

Still farther north the line of the reef diverges from the line of deformation. The former runs northwest, whereas the true fold continues toward the north. This throws the reef down so far on the west flank that it is unlikely to produce oil.

POROSITY IN LEA-WINKLER COUNTY AREA

There is a definite connection between the reef barriers and porosity. E. Russell Lloyd[1] has pointed out how porosity is formed in the reef itself by dolomitization of the original calcite of the reef. As the sediments grade toward more saline conditions on the shoreward side of the barrier, the secondary dolomite grades into primary dolomite, and this, in turn, into anhydrite. Porosity likewise decreases eastward until it disappears entirely in the anhydrite. In the Winkler County field the reef probably lies about 3 miles west of production. The porosity diminishes eastward across the field, the steep west flank fortunately being located far enough west to be within the zone of high porosity. Figure 3 shows that there is not sufficient structural closure to account for the accumulation of oil down to nearly 300 feet below sea-level (the water level in the field). Eastward gradation into anhydrite gives the closure in that direction.

In southern Lea County, as the reef diverges from the structural "high," porosity conditions on the latter become poorer. Porosity in the lime itself is probably so poor on the axis that monoclinal accumulation on the west may be found due entirely to decrease of porosity up dip. Wells from such accumulations can not be expected to compare with the large wells found in or near the reef limestone itself. The Marland's Lockhart well and the Empire's State No. 1 are examples of the former.

[1]E. Russell Lloyd, *op. cit.*

DEPOSITIONAL THEORY APPLIED TO OTHER LIMESTONE "HIGHS"

In the foregoing account certain features are suggested as indicating depositional "highs," and others indicate deformational "highs."

Thinning of the salt and red-bed section over lime structure is considered to favor the former. Such thinning can best be explained as due to actual differential deposition and differential compaction over a topographic elevation,[1] although the same result can be obtained by a growing anticline or by the sinking of basins around a stationary "high." The Panhandle arch is an example of the latter.

Where there is evidence that a "high" is partly depositional, the correspondence of the axis of the structure in the overlying beds with that in the lime is considered as evidence in favor of its being entirely due to deposition, as it seems unlikely that the depositional "high" would be located directly over the axis of deformation. It is thought that in such cases as the Getty pool the original location of the reef was influenced by some structural feature, possibly a terrace on the edge of the basin which was sinking on the east. In Winkler County the area east of the reef may be a positive element which originally located the reef, and later influenced the development of the deformational structure. However, such influence may be regarded as secondary when compared with the magnitude of the known depositional "highs."

An asymmetrical cross section likewise suggests, but does not prove, that a "high" is depositional.

Gradation of the lime section in the direction of the lesser dip strongly suggests deposition, rather than deformation, though it is possible for an anticline to form a barrier and cause a gradation toward saline conditions behind it.

Localized porosity is perhaps the best evidence of a depositional "high." In the San Andres limestone in the Maljamar and Artesia districts porous horizons can be traced both on and off structure throughout wide areas. This is in marked contrast to the porosity conditions described in the Winkler County field. The Artesia and Maljamar pools, especially the latter, are characterized by a fairly uniform section above the limestone.

The horizontal plan of the structures is a poor index of their origin, as both deformational structures and reefs may be long and narrow or short, broad, and *en échelon*.

[1] C. M. Nevin and R. E. Sherrill, "Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 1 (January, 1929), pp. 1-23.

Let us apply some of these criteria to two other limestone "highs" of West Texas.

The Yates "high" shows exceptionally high porosity. The beds above the lime thin over the structure, the axis in the upper beds corresponding with that in the lime. The structure is asymmetrical and is somewhat irregular in plan. Though the writer has traced no gradation in the lime series from the Yates pool itself, farther west the top of the lime seems to grade into anhydrite northeast of the Fort Stockton "high." This gradation is similar to that east of the Winkler County "high." It is probable that the Fort Stockton "high" swings eastward into the Yates pool. All of these features suggest a depositional "high" of reef origin and no deformation is necessary to explain any of the structural features.

The Big Lake "high" is more symmetrical than those already discussed. The porous oölitic horizon, from which oil is produced, is continuous both on and off structure. The lime section does not seem to be thicker under the structure than on either side. The structure is rather short and broad for a deformational structure, but is not unlike the closed domes produced by horizontal displacement and resulting shearing. If any of the limestone "highs" in the basin are due to deformation, this is probably one of them. Additional evidence of this is found in the deep well of the Texon, which is producing from sand far below the Permian, indicating that the lower beds are folded on the same axis as that of the limestone "high."

Other limestone "highs," notably that of Howard and Mitchell counties and that of Crane and Upton counties, show features of depositional "highs," but are located behind the Guadalupian barriers, where the waters were too saline for coral growth. They do not show the extreme porosity conditions of the line of the reefs, and it is thought that they may be due to abnormal deposition of limestone or dolomite along lines of currents or at the mouths of fresh-water streams. Each case, however, must be considered on its own merits.

RELATION OF DEPOSITIONAL "HIGHS" TO DEFORMATIONAL "HIGHS"

Reefs and other forms of depositional barriers are controlled by the depth of the water, which in turn governs the location of coral growth and controls currents. The Lea-Winkler County barrier apparently lies on the west flank of a major positive element, as shown by the deformational fold, which can be distinguished from the depositional "high." The remarkably uniform dip on the west flank of the Delaware Moun-

tain basin is an argument against the presence of any folding due to horizontal compression, so that it seems likely that the only deformational forces have been those of vertical uplift and of sinking basins. Exceptions to this statement, of course, include such deformation as the block faulting produced long after Permian time in the Sacramento and Guadalupe mountains, and the uplift of the Glass Mountains which lies along an old line of folding and does not parallel any of the trends in the basin near it.

STRUCTURE BELOW "BIG LIME"

Little is known concerning the structure of the beds below the "Big lime" in West Texas and southeastern New Mexico. The ultimate solution of the problem of the limestone "highs" is to be found in the structure of these underlying beds. Where the limestone maintains its thickness both on and off a "high," especially in the basin beyond the steep flank, the "high" may be regarded as due to deformation. The limestone may maintain its thickness on the gentler dip, and yet the "high" may be depositional. A greater thickness of limestone on the "high" than in the basin beyond it is conclusive evidence of its depositional origin.

In considering evidence of this nature, possible gradations of the beds below the upper part of the lime must be considered. For instance, it is likely that the upper part of the shale series which underlies the rather thin limestone section in Crockett County grades northward into limestone in the McCamey district in Upton County. The fact that 3,000 feet of limestone has been drilled in the McCamey field is, therefore, not conclusive evidence that the McCamey "high" is depositional. A similar example on the surface is the gradation of the sandstone and shale beds of the Word northeast into limestone in the Glass Mountains.

CONCLUSIONS

The limestone "highs" of the Permian basin may be due almost entirely either to deposition or to deformation, or they may be the result of a combination of the two. Where the "high" is asymmetrical and the fold in the beds above the lime corresponds with the lime structure, as in the Getty pool, deposition is the controlling factor. The Big Lake "high" shows characteristics of a deformational "high." In the Winkler County "high" a careful study shows the relative importance of deformation and deposition where the two have combined in forming the structure.

The ultimate solution in doubtful cases lies in deep drilling, to determine the structure of the beds below the lime.

TRIASSIC OF WEST TEXAS[1]

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Colorado, Texas

ABSTRACT

The Dockum series, of Upper Triassic age, overlies much of the oil-producing area in the southern part of the Permian basin, in West Texas and southeastern New Mexico. In the area south of the 33d parallel the Dockum consists of red and non-red conglomerate, sandstone, and shale beds of terrestrial origin. An examination of the series in well samples shows that it is composed of two formations. The names Santa Rosa and Chinle, as used for the Triassic of central New Mexico, are extended to include the equivalent formations in the Texas section. A critical study of the means used for separating the Red-beds of the Triassic and Permian shows that the gravel and non-lithified shales of the Triassic and the thick beds of very fine sandstone and hard shale of the Permian are the most prominent features.

INTRODUCTION

The study of the Triassic in West Texas is a problem both of subsurface stratigraphy and areal geology. In this paper are presented the data secured from the microscopic examination of well samples and from a less intensive examination of the outcrops. The presence of Triassic beds in West Texas has been recognized for approximately 75 years. Considerable geological work has been done in the region in that time, and since the discovery of oil, investigations have progressed rapidly. Early work on the Triassic was limited both in extent and accuracy by the paucity of fossils, the lenticular nature of the deposits, the remoteness of the region and the limited areal extent of the formation available for examination. A fairly complete understanding of the geology has been secured in the last few years. This is due in large part to the study of hundreds of sets of well samples. The ability to separate accurately the Triassic and Permian Red-beds and the recognition of the subsurface importance of the Triassic are direct results of the search for oil. Geologists commonly overlook the importance of the Triassic beds, probably because they furnish few horizons for contouring.

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, January 27, 1929.

[2]The California Company.

The Triassic formations were examined in the vicinity of Dockum, Dickens County, Texas, by W. F. Cummins in 1889, and by him described under the name of the "Dockum beds" in the First Annual Report of the Texas Geological Survey. The name Dockum series is here used to include all the Triassic beds in the Permian basin.

DISTRIBUTION

The 33d parallel is arbitrarily used as the northern boundary of the area to be discussed in this paper. This line passes along the northern edges of Eddy County, New Mexico, and Gaines, Dawson, Borden and Scurry counties, Texas. The accompanying map (Fig. 1) shows the distribution of the Triassic in this area. The boundaries are somewhat

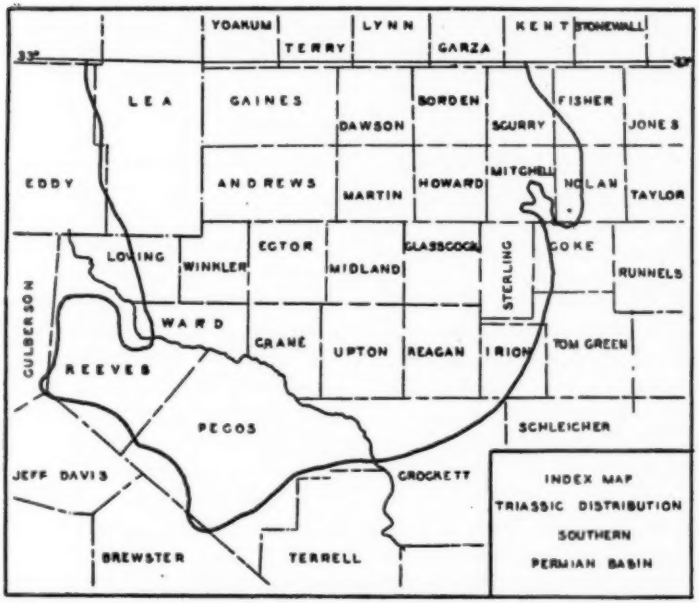

FIG. 1.—Approximate distribution of the Dockum series in the southern part of the Permian basin of West Texas and New Mexico.

hypothetical, because of the absence of properly-spaced wells, the scarcity of upper-hole samples from many wells, and the lack of detailed field mapping. The extent of the Dockum series, as known at present,

is determined by the size and shape of the original basin of deposition and by the modifications due to subsequent erosion. Triassic sedimentation was initiated by a considerable uplift of Llanoria, on the east, in Upper Triassic time. The first effects recorded of the Llanoria uplift are in the Mississippian of Arkansas and eastern Oklahoma. The uplift advanced progressively westward during the Pennsylvanian and Permian. In its final stages, in the Triassic or Jurassic, it probably extended as far west as Jones and Taylor counties in Texas. The Dockum series, a thick, terrestrial, flood-plain alluvial-fan deposit, was laid down on a west- and northwest-sloping, post-Permian terrain. Westward, in central New Mexico, these beds grade into other terrestrial sediments derived from the mountains of Colorado and northern New Mexico. The southern boundary of the Triassic is not well defined, but it is possible that it should be extended to include some of the west-dipping limestone gravels of the Glass Mountains.

The Dockum series has been subjected to at least three major periods of erosion. They are: pre-Comanche, post-Cretaceous, and post-Tertiary. No beds of Jurassic age are known in this southern Triassic area. The Comanche was deposited in a sea, advancing from the southeast, after the subsidence of the Llanorian land mass. Considerable parts of the Upper Triassic, especially at the eastern edge, were removed between the period of the Triassic deposition and the laying down of the Basement sand, the lowest Comanche in the area. Following the Cretaceous, mountain-building on the west again exposed the Triassic to erosion. During this period most of the Cretaceous and some of the Triassic were stripped off the plains area. All traces of the Dockum series were removed from the Sacramento and other ranges in southeastern New Mexico. Following this period of early Tertiary erosion, it is probable that most of the Triassic was covered by later Tertiary beds. At present, Pecos River and the rivers north of Mitchell County have cut through the Tertiary and Cretaceous caps and the Triassic is being slowly removed.

LITHOLOGY

The Dockum series is composed predominantly of clastic sediments,—sandstones, shales, and conglomerates. Small amounts of chemical and organic sediments occur with the clastics. The sandstones range in texture from fine to very coarse. The sorting is poor and the coarser grains grade imperceptibly upward into fine gravel. The sands become finer toward the west, away from their source of supply, but at no place are they as fine as the sands of the underlying Permian. They are com-

posed predominantly of quartz with minor amounts of feldspar and mica and a good crop of heavy minerals. The color ranges through white, yellow, amber, and red. The generally red color of the sediments is due more to the presence of red shale cement than to the color of the separate grains. Grays andstones are very common along the eastern margin, and farther west the water-bearing sands are ordinarily gray. In some parts of Upton and Lea counties deposits suggesting sand dunes have been penetrated in drilling. The deposits which are considered dunes consist of beds with a maximum thickness of more than 30 feet, composed entirely of medium to coarse, sub-round, partly frosted quartz grains. The dune sands are commonly amber or red, although a few clear grains occur. Few of the Triassic sandstones are well cemented. Surface hardening is encountered on many exposed surfaces, and a few beds of stone are being quarried for building purposes. Cementing materials include gray and red shale, limestone, silica, gypsum, and iron oxide. Black and white mica are common in the sands in many parts of the area. They are more characteristic near the eastern margin. Sandstones are much more prominent in the lower than in the upper part of the series. The sandstones in the lower sandy part of the Dockum seem to form fairly continuous beds. Those in the upper part are evidently discontinuous lenses. In eastern New Mexico these upper sand lenses are much more extensive than in Texas. Probably they were laid down by abrading streams near the outer margin of a wide alluvial fan. Water horizons occur commonly in the lower sandy phases of the Triassic. The water sands are ordinarily fairly coarse and free from shale. Many of them contain gypsum and euhedral calcite crystals. In parts of Mitchell, Howard, Glasscock, and Reagan counties, a water-bearing sand occurs at the base of the Triassic. The occurrence of this water horizon is too irregular to be trusted for correlation purposes without a study of sample logs of each well.

The shales of the Dockum series are generally red, but appreciable amounts of non-red shale are present. The non-red shales occur most plentifully in the middle and lower parts of the series. They are more common near the eastern edge, but are encountered throughout the Triassic area. The color range includes gray, green, blue, yellow, and brown. The red and non-red shales are similar lithologically. They are unlithified, dense, resinous or micaceous, and many are sandy. The shales are commonly variegated or mottled. The red shales range from reddish-brown through brick-red and maroon to purple. The main shale beds occur in the upper part of the Dockum series, but shale is

common in the lower sandy part. Beds of nearly pure shale ranging from 600 to 1,200 feet in thickness overlie the sandstones in the central and western parts of the area. In the outcrops the shales are not prominent. They are ordinarily covered with talus and are exposed only in the ravines. In well samples they are commonly poorly preserved, because of their poor lithification.

The Triassic gravels are of two types. The first type includes those pebbles and boulders which owe their presence to the short distance they have been transported. In this group are the limestone and dolomite gravels, the shale and anhydrite pebbles and the blocks of soft Permian sandstone. Conglomerates of this type are limited to the lower beds on the southern and eastern margins of the basin. They decrease rapidly in importance away from their sources. The second type of conglomerate includes those composed of resistant materials which are only slightly affected by attrition during their transportation. These are the chert, quartz, quartzite, and silicified-wood pebbles. Pebbles of this type predominate in the conglomerates in all parts of the basin. They occur, to the exclusion of all others, in the gravels, above the basal conglomerate, in the central and western parts of the area. Even these hard pebbles are reduced somewhat in size during transportation. The average size is much smaller in Reeves, Ward, Loving, and Lea counties than in Mitchell and Scurry. Igneous pebbles are scarce in the Triassic. They seem most common at the southern end of the area, but even there they are very rare. Silicified wood is common and probably originated in the Triassic. Silicified trees and stumps have been observed on the outcrops in many places. Quartz and chert pebbles are extremely common. Much of the chert was probably derived from the Pennsylvanian and Permian limestones on the east, or from the outcrops of the San Angelo formation. The presence of re-worked San Angelo conglomerate may account for the similarity of the Triassic and San Angelo gravels of Coke County, where the outcrops are only a few miles apart. Some of the gravel at the western edge of the Dockum area may have been derived from the mountains of northern New Mexico or Colorado, but it is more probable that most of it came from the south and east. Gravels are mostly limited to the lower sandy phase of the Dockum series, but isolated pebbles and thin beds of gravel do occur in the upper shales.

SEDIMENTATION

The retreat of the Permian sea was followed by erosion and local folding. In some places the Triassic rests directly upon the Permian

anhydrite, but ordinarily some Permian Red-beds intervene. Erosion can not have been very extensive because most of the Permian structures are reflected in the base of the Triassic. Local irregularities in the Triassic-Permian contact, however, are more probably the result of erosion than of folding. The comparative thickness of the Quartermaster suggests that not more than 400 feet of upper Permian Red-beds were removed from any locality. In some wells brown, sandy, organic clays occur at the contact of the Permian and Triassic. These probably represent soil. The Dockum series was laid down on the gently-folded beds of an eroded and partly soil-covered plain. Deposition followed a considerable uplift on the east in Upper Triassic time. No Lower or Middle Triassic beds are known in this area. Following the uplift large quantities of sand and gravel were carried down out of the mountains. Most of the coarse material accumulated in alluvial fans near the eastern edge of the plain. Some of the sands and gravels were carried down the gentle west slope for long distances. The source of the Triassic sediments was evidently the Paleozoic rocks cropping out on the east and south. These were probably deeply weathered and easily removed. This large amount of readily available material caused overloading and consequent meandering of the streams. The meandering allowed the flood plains to be built up uniformly. Following the reduction of the mountains, only the finer material was transported by the streams flowing with reduced gradients and the thick shale beds of the upper Dockum series were deposited. Calcareous beds were laid down during all stages of deposition. Limestone occurs as pebbles, concretions, lenses, and fairly extensive beds in all parts of the Dockum series. The limestone gravels are limited to the eastern and southern edges of the deposit. This suggests that the limestone terranes were exposed in the mountains on the east and south. The streams which flowed over the exposed limestones in the uplands carried lime in solution. This lime was deposited as travertine, caliche, calcareous shale, or limestone cement for the sands, while the streams were flowing across the Triassic plain. Some dolomite occurs in place of limestone. The evidence of all these observations suggests that the dolomite was deposited as gravel. The phosphates, which are very common in the Triassic, were probably derived from the decay of marine limestones, although some may have come from the bones and excrement of the numerous land animals.

The Dockum beds are not desert deposits. They were laid down in warm regions of moderate rainfall. The humidity is shown by the large amount of fossil plants and the common occurrence of vertebrate

and invertebrate remains in the outcrops. The transportation of the material for such a thick and extensive series required a large amount of water. Much of the water may have been supplied by the mountains on the east, but some fell as rain on the plains. The depositional period was one of quiescence in the basin. Folding evidently preceded and followed deposition instead of accompanying it, although there may have been some subsidence in the center of the Permian basin. This would account for the great thickness of Triassic sediments laid down in that part of the area.

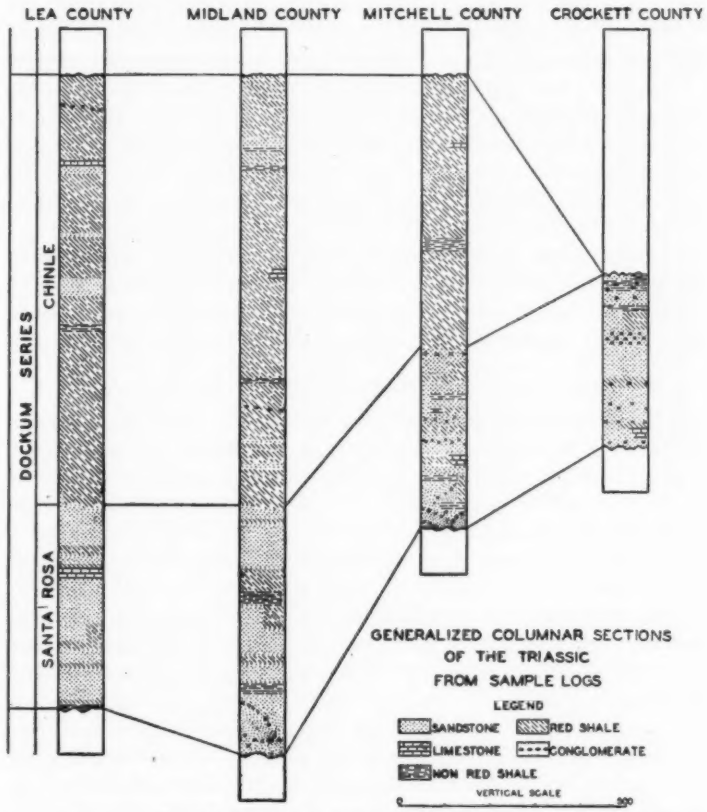

FIG. 2.—Generalized columnar sections of the Triassic from sample logs. Vertical scale in feet.

STRATIGRAPHY

Several methods of dividing the Dockum series into formations have been proposed. In subsurface work two formations can be recognized on the basis of lithology in the central and western parts of the area. The lower is a sandstone formation whose average thickness is 350 feet, but whose maximum is 600 feet, or more. Well samples show that this sandstone, correlated northward, is the Santa Rosa sandstone of north-central New Mexico. Overlying this basal Santa Rosa sandstone is a shale formation. Its maximum thickness is approximately 1,200 feet, and it is composed of shale with minor amounts of sandstone, limestone, and conglomerate. This shale bed occupies the same stratigraphic position as the Chinle formation of New Mexico. The contact of these two formations is a somewhat indefinite zone. The two can ordinarily be separated in well samples without difficulty, but the contact does not seem to have any stratigraphic significance. Only the Santa Rosa is present at the southern and eastern margins of the Triassic area. This is true in Pecos, Crockett, Irion, Sterling, Mitchell, Scurry, Fisher, Nolan, and Coke counties. Local names, such as Quito, Taylor, Dripping Springs, Barstow, and Camp Springs, have been applied to some of the more prominent sandstones in different areas. The beds to which they are applied can not be recognized throughout any extensive area. This is to be expected from the lensing nature of terrestrial deposits.

IDENTIFICATION

The differentiation of the Triassic from the underlying Permian Red-beds is a problem of considerable importance. The principal difficulties in distinguishing the two are: (1) the uniform absence of fossils, especially in well samples, (2) the general red-bed character of both, and (3) the absence of a sharp lithologic break or basal conglomerate. The following criteria have been found useful in separating the two systems.

1. The most definite criterion for differentiating the Permian from the Triassic is the presence of bedded anhydrite and salt in the Permian. Gypsum and anhydrite do occur in the Triassic, but only in decidedly minor amounts.

2. Clear, well-rounded, frosted quartz grains in a matrix of very fine sandstone are characteristic of the Permian. The frosted quartz grains of the Triassic are generally colored, sub-rounded and only partly frosted. Extensive beds of very fine sandstone with silica, shale, or an-

hydrite cement are common in the upper Permian. Beds of very fine sandstone are rare in the Triassic.

3. The clastic sediments of the Triassic show a wide range in texture and composition. Conglomerates, pebbly sandstones, and coarse sandstones occur mixed with the fine sandstones and shales. The Permian clastics are homogeneous and gravel is very rare except in the San Angelo and Rustler formations. The size of the pebbles of the Dockum ranges from fine to coarse and many are subangular. The Permian gravel in well samples is fine and ordinarily well rounded.

4. In many parts of the basin the coarse sediments of the Triassic section carry several water horizons. Away from the outcrops the waters may be brackish or salty, but water sands are much more plentiful in the Triassic than in the upper part of the Permian.

5. In the eastern and southern parts of the Triassic area conspicuous amounts of non-red shale and sandstone occur in the Triassic. Similar beds of non-red shale and sandstone are rare in the upper Permian, although gray mottles suggesting leaching are common.

6. One of the most characteristic features of the Triassic is the poor lithification of the shales. The upper Permian shales are, in comparison, very hard and compact. This difference is probably due to the high colloidal content of the Triassic. The character is well shown by the speed with which the different shales decompose in water.

7. Color differences are commonly mentioned as distinguishing features of the Triassic and Permian Red-beds. The red of the Triassic is more of a maroon, in places tinged with purple; the red of the Permian has more brownish qualities. Almost any gradation of color can be found in both. The color criterion seems to be more useful in the outcrops than in well samples.

The presence of mica is commonly regarded as an important distinguishing feature of the Triassic. Care should be used in applying this criterion. Although mica is much more plentiful in the Triassic than in the Permian, its presence in the latter can not be readily determined petrographically. With a hand lens or even with binoculars it may be difficult to distinguish between mica and thin flakes of gypsum. Gypsum flakes are almost as plentiful in the upper Permian sands as mica in the Triassic. Moreover, mica is not universally present in the Triassic. Beds of non-micaceous shale are common in the Chinle. For these reasons it seems best to stress other, more definite criteria.

9. A phosphate test of the shales ordinarily shows phosphorus in the Triassic. If the upper part of the hole is uncased, enough Triassic

shale may be carried down to give a strong phosphate test on typically Permian sediments. For this reason samples should be thoroughly washed before applying the test. Phosphates seem to be most common in the shales and calcareous beds. The sandstones are generally poorly cemented and it is probable that most of the phosphatic material which may have been present was washed out in the drilling. The phosphate occurs commonly in calcareous nodules and concretions.

10. Limestone, calcareous shale, and calcareous sandstone are characteristically Triassic. Dolomite may be either Triassic or Permian. The limestone seems to occur as bedded deposits, conglomerates, and concretions.

Of the criteria here listed the lithification of the Permian shales and the change from the heterogeneous sandstones of the Triassic to the very fine sandstones of the Permian have been found to be the most useful. These criteria do not require any special equipment and are easily applied. Ordinarily there is no difficulty in separating the two systems in the field. Here the presence of bones, gravel, limonitized and silicified wood, and plentiful mica in the Triassic, and the thin uniform bedding of the Permian are sufficiently characteristic. In limited outcrops where the stratigraphic position is not apparent the same criteria may be used as in determining well samples.

IMPORTANCE

The maximum thickness of the Dockum series is approximately 1,500 feet. This makes it one of the most important members of the stratigraphic column in the Permian basin. The series has an extensive surface and subsurface distribution, overlying part or all of every large oil field in the basin. As the Dockum beds are terrestrial deposits it is possible that no oil was generated in them. But under exceptional conditions it is possible that the sands may be found to act as reservoirs for commercial accumulations of oil. In a general way, correlations can be made between the beds of the Dockum series. Little dependence should be placed on correlations thus established, because most of the beds are very lenticular and also because very similar beds occur at different horizons. Although few of the folds of the Triassic coincide with those of the Permian, the base of the Triassic ordinarily reflects the underlying structures, modified and softened by post-Permian erosion.

DISCUSSION

BRUCE WHITCOMB, Fort Worth, Texas: What is the difference in the heavy-mineral content between the Triassic and Permian?

JOHN EMERY ADAMS: There is a difference, but at present I am not prepared to make a statement.

BRUCE WHITCOMB: Have you been able to differentiate horizons above the contact that can be used as indicators of the elevation of the top of the "Big lime?"

JOHN EMERY ADAMS: Horizons in the Triassic give only a rough indication of the position of the top of the "Big lime."

E. F. MILLER, Tulsa, Oklahoma: I should like to ask Mr. Adams if there is present in the West Texas region a sand conglomerate in the middle of the Dockum series approximately 400 feet above the Santa Rosa sandstone. This horizon is called the Trujillo sandstone in the Tucumcari region, and is recognizable even as far west as Fort Defiance on the Arizona-New Mexico line northwest of Gallup, New Mexico.

JOHN EMERY ADAMS: So far, no such zone has been recognized. In the Triassic south of the 33d parallel, no extensive conglomerates or sandstones occur in the Chinle shale.

DISCUSSION OF PERMIAN SYMPOSIUM[1]

CHARLES LAURENCE BAKER[2]
Houston, Texas

The later Paleozoic strata of the Permian basin, or Llano Estacado geosyncline, afford perhaps more problems in nature, origin, and correlation than any other assemblage of post-Algonkian rocks of the continent. The reasons are two-fold. (1) In an area of about 200,000 square miles they are buried from sight. (2) The Permian sediments were deposited under extraordinary conditions, on a scale unprecedented, and are exceptionally localized.

We do not know the existing northern limits of the basin. We can only conjecture the original borders. We do not know the thickness of the Permian, nor do we know anything concerning the nature of the underlying Pennsylvanian within the heart of the basin. We have a few scattered continuous drill cores of the upper part of the Permian, and pulverized drill cuttings gathered with more or less accuracy from a relatively large number of borings. As yet, there are not sufficient fossils from the bordering exposures to enable us satisfactorily to correlate even the rocks exposed, and those beneath the surface are known to differ surprisingly both laterally and vertically.

Under the circumstances there is open to the mind a rare field for philosophic speculation, the sort of speculation which has been aptly defined as the "seeking of a blind man in a totally dark chamber for a black cat." It is, therefore, not surprising that it is difficult to find any two investigators who are in agreement.

A sufficient knowledge of facts will be obtained only when a requisite number of continuous cores to the base of the Permian have become available. The problems of the surface strata in the Guadalupe Mountains can, however, be solved with certainty. All they require are field observations and deductions of painstaking accuracy with the aid of an accurate topographic base map. But solution of the Guadalupe Mountains problems will by no means suffice for the buried part of the Permian basin. It will, however, clear up the most doubtful area of surface exposures. The problems of the Guadalupe Mountains exposures have to do largely with origin and correlation. Facts, not opinions, are needed in this connection.

The issue most stressed at the Fort Worth meeting was the so-called "Big lime" of the basin proper, its nature, its origin, and its correlation. We should take into consideration, however, that it is not probable that the "Big lime" is a unit or a single horizon. It seems certain that the lithology is diverse.

It is perhaps impossible to over-emphasize the importance of the surroundings of the "Big lime," whether a unit or a collection. The exposures in the

[1]Discussion of papers presented before the Association at the Fort Worth meeting March, 1929. Manuscript received by the editor, June 24, 1929.

[2]Chief geologist, Rio Bravo Oil Company.

Guadalupe, Delaware, Apache, and Glass mountains—which are nearest the "Big lime" of the basin—certainly exhibit evidences of passage from west to east and from south to north from marine limestone of substantially normal facies into precipitates of saline residues. The latter occupy the place of marine limestones in more normal environment. Similarly, from east to west the passage is from saline residues (among which we include the calcium-magnesium limestones of varying proportions of those elements, non-fossiliferous, and best described as "rauchwackes") into the "Big lime" facies, which is apparently in part itself composed of saline residues. It is an undisputed fact that the uppermost Permian limestones of the Guadalupe, Delaware, Apache, and Glass mountains pass in part in basinward outcrops into saline residues. It is equally indisputable that the "Big lime" is overlain with saline residues. It seems certain that in places the "Big lime" dovetails into saline residues, also that, at least locally, interbeds of saline residues occur in the "Big lime" itself. Combined with these significant facts is another equally pertinent under the circumstances, which is that the "Big lime" has proved to be almost barren of fossils,—at least of well-preserved, identifiable fossils. This latter fact might be regarded as fortuitous because of dolomitization and other effects after deposition, but when considered with the medium of saline residues in which the "Big lime" is situated, it is valid complementary evidence of the origin of the "Big lime."

The hypothesis of organic reef origin—not origin from autochthonous organisms, but from those transported by waves and currents at least in part after their death—is most probable in the uppermost Permian carbonates of the Glass Mountains, and for the southwestern part of the probably contemporaneous rocks of the Guadalupe Mountains. With more probability they may be current or barrier reefs; it is less probable that the organic remains occupy the exact sites of their death. The serious objection to the theory that they are coral reefs is that they contain relatively few corals or none, although they do contain remains of other organisms. But perhaps no one seriously maintains that they are coral reefs in the strict sense, but merely that they are organic reefs. These sediments of the mountain outcrops are in all probability close to regions of normal sea conditions.

When we consider the more or less reef-like, or perhaps better, greatly extensive lenses or tongues of carbonates within the basin itself, the lion barring the way to the theory of organic origin is the surrounding, overlying, and in places, at least, interbedded saline residues. It would be foolish as well as not strictly accurate to regard these carbonates as entirely unfossiliferous. They may ultimately prove to grade southward or westward into more fossiliferous contemporaneous deposits. Also some organisms, and among them certain mollusks, can live in water of abnormal salinity. It is also within the realm of the possible that some organisms of the Permian could have become adapted to existence in abnormally saline waters while their modern representatives are not so adapted. There is some danger in assuming that the adaptation and environment of a particular clan of organisms has perforce remained essentially the same throughout geologic time. That is, perhaps, placing an undue strain upon evolution.

It is the writer's view that there is at least one alternative hypothesis contained in a paper now in press and presented before the Houston Geological

Society at a time shortly before the Fort Worth meeting.[1] This is to the effect that the "Big lime" facies was not an organic carbonate, but a precipitation, essentially inorganic; a saline residue, akin in its origin to the chlorides, sulphates, and other saline residues of the basin. It was deposited because afferent currents entering the basin from the normal sea and containing carbonates in solution became supersaturated for carbonate upon reaching basin waters so saline that they had lost their own original carbonates and were so highly saturated that they were depositing either sulphates or chlorides (anhydrite [gypsum?], salt, et cetera), or at least could not carry any great amount of carbonates in solution. The thickest and most extensive lenses or tongues of carbonate sediments would be laid down either along the courses or at the peripheries of such afferent currents, or as barrier reefs or deltas. In the latter case there would be marginal circulatory currents or dilution by fresh-water streams along or near the shore line. Part of the carbonates may have been derived, not from the normal sea directly, but from the solution of limestones in land areas tributary to the basin. It is judged possible under such conditions that more or less modified and relict faunas may have survived, especially in littoral areas where fresher waters were supplied either by littoral currents or by the inflow of streams from the land. Even where a current entered the very heart of the basin, such a current would emerge from the open sea laden with ordinary organisms and some of the organic remains would be strewn on the bottom by current action for a considerable distance beyond the point where the organisms would be killed by abnormal salinity. Also the fresher water and its living organisms would float for considerable distances upon more saline water, because of the remarkable fact that diffusion of saline content is very far from being complete even in the midst of the present-day oceans; hence, an absolute lack of organic remains is scarcely to be expected.

The remainder of the hypothesis will be briefly considered here. It has mainly to do with the climatic implications. The associated red beds were not formed in an arid climate. They may, it is true, have been transported from a humid to an arid region and yet retain their coloration. But this is not adjudged necessary. So long as the total evaporation exceeds total water supply from all sources, gradual concentration of saline content takes place in any sort of basin, bay, or gulf. Sulphates and chlorides are now being precipitated along the northwestern shores of the Gulf of Mexico, where the annual rainfall varies at different localities from 20 to 35 inches. Probabilities must not be mistaken for certainties, and no one can successfully deny that saline residues are deposited in arid climates; but the writer has been for a long time convinced that aridity is not necessary for their deposition. In the present state of knowledge it appears more probable that the Permian Red-beds and saline residues constitute an association for the formation of which it is unnecessary to postulate strictly arid climatic conditions. In the writer's opinion, the average rainfall on the total Permian basin, both land and water area, may have been even as great as 40 inches annually, or even more if the temperature and wind conditions were in the main comparable with those of the same region to-day. Rainfall might have been more in the surrounding highlands

[1] Charles Laurence Baker, "Depositional History of the Red Beds and Saline Residues of the Texas Permian." *Pub. of Univ. of Texas Bur. Econ. Geol.*, in press.

and less in the lowlands and desiccation basin. We can successfully rule excessive cold out of the Permian basin during Permian time. An Arctic climate would not have permitted red beds to form; it could scarcely have been favorable for precipitation of saline residues on so vast a scale. The vastness of the phenomena of the Permian basin is one of the facts which must ever be kept in mind. A long time and extensive uniformity in conditions are presumably involved. This does not mean, however, that there were not important secular changes, of which, indeed, there are already at hand remarkably plentiful evidences.

The view that the Yeso and San Andres are the age equivalents of the Guadalupe groups can scarcely be accepted at present. The fauna of the San Andres is totally different from that of the Guadalupian and markedly less advanced in evolution. Also, the fauna of the Bone Springs limestone, which lies beneath an unconformity at the base of the Delaware Mountain, is different from that of the San Andres, and younger.

It is more probable that it will ultimately be found that the Manzano and Guadalupian groups are separated either by an unconformity or by a fault, of the gravity or of the thrust type. Such unconformity or fault is probably difficult to detect, as it separates limestones of more or less similar lithologic character, and subsequent solution and re-precipitation has obscured the fault-breccia or conglomerate denoting unconformity; or it may be found that the San Andres passes with conformity beneath the Bone Springs or older strata.

The alternative explanation, already advanced by the U. S. Geological Survey workers, is that the two groups are contemporaneous. This is possible. Yet it would mean a peculiar condition—nothing short of absolute isolation of a relict middle Wichita fauna in a basin of its own for a long period of time.

The preceding is an argument the true value of which can be fully appreciated only by paleontologists or by those with sufficient paleontological knowledge to realize the significance of fossils. There is, however, another argument which can be appreciated by all geologists and which, strangely enough, has not been advanced heretofore. It is so simple and reasonable when once stated that it should be widely accepted.

The Delaware Mountain formation in the northern part of its outcrop in the vicinity of Guadalupe Point consists very largely of sandstone. G. B. Richardson states in his first publication:[1] "The northern part of the slope (of Delaware-Guadalupe Mountains) is prevailingly sandy, while southward the rock is almost all limestone." This is a fact confirmed by subsequent investigators as well as by Richardson himself (in the Van Horn folio.[2]) It is accordingly reasonable to suggest that the Delaware Mountain sandstone and shales in the vicinity of Guadalupe Point and for some distance east and south may be of marine deltaic origin, and as they are non-red in color they may have been derived either from a more arid source than the Permian Red-beds or from a source undergoing such rapid erosion that mature weathering did not

[1] "A Reconnaissance in Trans-Pecos Texas North of the Texas and Pacific Railway," *Univ. of Texas Mineral Survey Bull. 9* (1904), p. 39.

[2] *U. S. Geol. Survey Folio 194* (1914).

take place. That vast quantity of sand did not originate from the weathering of limestones.

Now if the Delaware Mountain thick and extensive detritals are a part of the Manzano group, we are confronted with a most remarkable fact which the writer, at least, does not know how to explain. That fact is that the Delaware Mountain detritals are known to be surrounded in every direction except basinward by limestones or saline residues which are considered to be contemporaneous Manzano by advocates of the view that the Manzano is equivalent to the Guadalupian. We will not take space here to detail the evidence but merely list the works in which it may be found:

1. N. H. Darton, "Red Beds and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), p. 220, latter part of first paragraph; pp. 220-27.
2. G. B. Richardson, "A Reconnaissance in Trans-Pecos Texas North of the Texas and Pacific Railway," *Univ. of Texas Mineral Survey Bull. 9* (1904).
3. G. B. Richardson, *U. S. Geol. Survey Van Horn Folio 194* (1914).
4. J. W. Beede, "Notes on the Geology and Oil Possibilities of the Northern Diablo Plateau in Texas," *Univ. of Texas Bur. Econ. Geol. Bull. 1852* (1918).
5. J. W. Beede, "Report on the Oil and Gas Possibilities of the University Block 46 in Culberson County," *Univ. of Texas Bur. Econ. Geol. Bull. 2346* (1923).

It is a fact beyond dispute that the sandstones of the Manzano (Yeso and San Andres), quantitatively not comparable, by the way, with the Delaware Mountain sandstones, gradually thin out southward in the southern Sacramento and northern Guadalupe Mountains, and that the underlying detrital Abo, as observed both by Darton and by the writer, thins and disappears southward before the Texas-New Mexico line is reached.

It is evidently a sheer impossibility that the Delaware Mountain sandstones can be contemporaneous with the so-called Manzano limestones and saline residues entirely surrounding them, and, so far as we now know, with limestones both underlying (Bone Springs limestone) and overlying them (Capitan limestone), except under one condition, that somewhere near Guadalupe Point, northeast, north, or east of it, a relatively high land area of older rocks, largely of either detrital sediments or crystallines, was undergoing active erosion in Delaware Mountain time. This is a possibility, but it is open to two rather serious objections. One is that there is no evidence indicating a plentiful source of sand in any older sediments, which so far as can be judged from outcrops contain very little clastic material, and the Delaware Mountain sandstones are not truly arkosic, as they probably would be if derived from near-by crystalline rocks. The indications are that the Delaware Mountain sandstones came from a distant source, more probably from crystalline rocks, possibly from Magdalena, Abo, or Manzano. The other objection is the lack of sandstones in the nearer outcrops of the Manzano supposed correlative of the Delaware Mountain, although the strata are buried from view on the northeast and east.

However, we do have a correlative of the Delaware Mountain sandstones elsewhere. This is in the Word formation of the Glass Mountains, which in the southern part of its outcrop ranges from 1,200 to 1,500 feet in thickness

and which according to Udden contains 40 per cent of sandstone, an estimate made from the study of the entire outcrop of that formation. The fauna of the Word has been regarded by all its investigators as practically equivalent to that of the Delaware Mountain. The Word is underlain by a thick series of fossiliferous Permian, including the Manzano faunal equivalent, and directly underlain by the Leonard, the fauna of which, according to competent investigators—Beede, Schuchert, and the King brothers—is identical with the fauna of the Bone Springs limestone, which formation directly underlies the Delaware Mountain. And the Word is overlain by thick limestones very similar lithologically to the Capitan, which latter overlies the Delaware Mountain.

The preceding objections to correlation of the Manzano with the Guadalupian, although not exactly insuperable, are of great weight.

Another published correlation, leading to the same final conclusion as the one just considered, is that of the supposed San Andres in the Marland Bell Ranch well No. 1 in San Miguel County, New Mexico, with the Blaine of the Texas Panhandle.[1] It is not entirely certain that what is called the San Andres in the Bell Ranch well is really the true correlative of that formation, although it may very well be so and still not be the correlative of the Blaine. It is the correlation of strata in this boring with the Santa Rosa and with higher Triassic above the Santa Rosa to which perhaps more valid objections can be made. The strata above those referred to the Santa Rosa contain two limestones. The only limestone found on the surface which may be referred to the Triassic in northeastern New Mexico is a thin limestone bed constituting the so-called Todilto, which most workers assign to the Jurassic. At least no limestones are known to be present in Triassic strata beneath the Todilto, and the limestones in the boring are beneath the Todilto horizon. Forty-five miles southwest of this boring there occurs a succession of beds of nearly the same thickness which include the two limestones in the same position, and definitely known to be overlain unconformably by the Santa Rosa, or basal Trias, a second proved unconformity occurring at the base of this limestone succession.

The supposition is that this succession is Permian and the unconformity at the base may be the unconformity at the base of the San Angelo on the eastern side of the Permian basin. If this particular succession be considered to be the possible correlative of the Blaine of the Panhandle, it would seem to be more in line with the probabilities.

It is quite natural that many attempts are being made to correlate the Permian throughout the basin. Great caution is desirable. For example, in the two sections last mentioned, both within the basin and only 45 miles apart, the Bell Ranch section has only one thin bed of anhydrite and a single thicker bed of underlying salt, separated by predominating limestone, and the other section shows 14 cycles of anhydrite-salt deposition and a total of more than 600 feet of anhydrite and of more than 600 feet of salt in the same stratigraphic group. Other examples of as striking differences are listed in the writer's forthcoming paper.

The Permian basin is one of the very great geologic units of the world. It is a quarter of a million square miles in extent. Saline residue deposition

[1]Charles N. Gould and Robin Willis, "Tentative Correlation of the Permian Formations of the Southern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927), pp. 431-42.

has taken place on a scale perhaps unprecedented. On both east and west basin margins, deposition was markedly irregular and deposits localized, lenticular, and wedge-shaped. We know as yet relatively little of real conditions in the heart of the basin, now buried from view. Purely lithologic correlations between western and eastern marginal deposits are extremely dangerous, and correlations based on drillers' logs within the basin, if anything, more dangerous. As is generally true, the fossils may be expected to have the final word. It is reasonable to expect discovery of more diagnostic fossils in strata later than Wichita when a really diligent and exhaustive search by experienced collectors has been made.

GEOLOGICAL NOTES

FIRST AUTHENTIC CRETACEOUS FORMATION FOUND ON GULF COAST SALT DOMES OF TEXAS[1]

For the past few years geologists have suspected that Cretaceous sediments were present at great depths in the Gulf Coastal region of Texas and that the salt found in the salt domes in this region has its source in formations as old as, or older than, Cretaceous.

This suspicion was not verified until May 1, 1929, when a solid 35-foot core section of marl of Upper Cretaceous age was taken by the Navarro Oil Company of Houston, Texas, from their Community No. 4 on the northeast side (Fig. 1) of the South Liberty salt dome, 2.5 miles south of Liberty, Liberty County, Texas (Fig. 2). This well is 207 feet east and 50 feet south of the northwest corner of their Adlawyer Baldwin *et al.* (Community) 15-acre lease.

Heretofore upper Eocene sediments were the oldest known formations penetrated in the Gulf Coast salt dome area of Texas in spite of the fact that approximately 1,000 wells have been drilled, some to a depth of several thousand feet, and all of them have been completed either in Tertiary sediments, limestone cap rock, gypsum and anhydrite cap rock, or salt.

The 35-foot section of Cretaceous rock is part of the cap rock. It is 79 feet below the top of the limestone cap rock and 50 feet above rock salt.

The formations encountered above the cap rock in the drilling of the Navarro Oil Company's Community No. 4 range from Recent to Eocene in age.

The section is as follows:

Depth in Feet	
0 to 1,158	No samples
1,530	Miocene
1,780	No samples
1,849	Oligocene (*Heterostegina* zone)
1,853	Oligocene (*Marginulina* zone)
1,923	Basal Jackson (*Bulimina* zone)
1,943	Yegua (upper Claiborne)
2,012	TOP OF CAP ROCK. Fairly hard, brown and gray, cavernous, oil-stained, slightly dolomitic, crystalline limestone with clay impurities. (A few Upper Cretaceous *Foraminifera*)

[1]Published with permission of the Navarro Oil Company and the Humble Oil and Refining Company.

2,022	No samples
2,057	Gray, fossiliferous marl of Upper Cretaceous age
2,065	Pulverized, slightly dolomitic, crystalline limestone. No fossils
2,085	Brown, oil-stained, porous, slightly dolomitic, crystalline limestone. No fossils
2,102	No samples
2,107	Anhydrite with traces of dolomite and calcite
2,120	Coarsely-crystalline rock salt. Well was abandoned on May 5, 1929, in salt at 2,120 feet

F. W. Rolshausen, in charge of the paleontological laboratory, Miss A. C. Ellisor, research paleontologist, and E. P. Tatum, Gulf Coast paleontologist, all of the Humble Oil and Refining Company, recognize the *Foraminifera* from the Cretaceous rock in this well as being indigenous and of Upper Cretaceous age. The lithology of these samples was so characteristic of Cretaceous sediments that L. T. Barrow, chief geologist for the Humble Oil and Refining Company, upon casual examination and without knowing the locality, stated they appeared to be an intraformational conglomerate of Upper Cretaceous age.

There are more than fifty species of *Foraminifera* in the marl section from the Community well No. 4 between 2,022 and 2,057 feet. This association of *Foraminifera* is characteristic of Upper Cretaceous sediments, and individual species are identical with those familiar to paleontologists dealing with Upper Cretaceous problems. Due to the lack of literature on Cretaceous *Foraminifera* there are several species that are not listed.

The *Foraminifera:*

Globotruncana arca (Cushman)
Globotruncana rosetta (White)
Globotruncana conica (White)
Globotruncana canaliculata (White)
Globorotalia membranacea (Ehrenberg)
Gyroidina comma (White)
Gyroidina simplex (White)
Lenticulina nuda (Reuss)
Anomalina grosserugosa (Gumbell)
Verneuilina rotunda (White)
Lenticulina reniformis (d'Orbigny)
Bulimina ovula (Reuss)
Gyroidina minuta (White)
Rotalia beccariiformis (White)
Gyroidina subangulata (White)
Gyroidina anomalinoides (White)
Pullenia coryelli (White)
Nonion scapha (Fichtel and Moll)
Frondicularia elongata (Cushman)
Textularia nacataensis (White)
Clavulina trilatera (Cushman)
Spirillina vivipara (Ehrenberg)
Nodosaria fontinensis (Berthelin)
Nodosaria communis (d'Orbigny)
Guembelina globulosa (Ehrenberg)
Guembelina ultimatumida (White)
Guembelina globifera (Reuss)
Guembelina excolata (Cushman)
Guembelina elegans (Rzehak)
Guembelina pupa (Reuss)
Pseudotextularia varians (Rzehak)
Nodosaria laevigata (Nelson)
Rotalia cretacea (Carsey)
Globigerina voluta (White)
Globigerina bulloides (d'Orbigny)
Globigerina cretacea (d'Orbigny)
Oölina emaciata (White)
Turrilina trochoides (Reuss)
Pleurostomella subnodosa (Reuss)
Eouvigerina cretacea (Heron-Allen and Earland)
Ostracoda

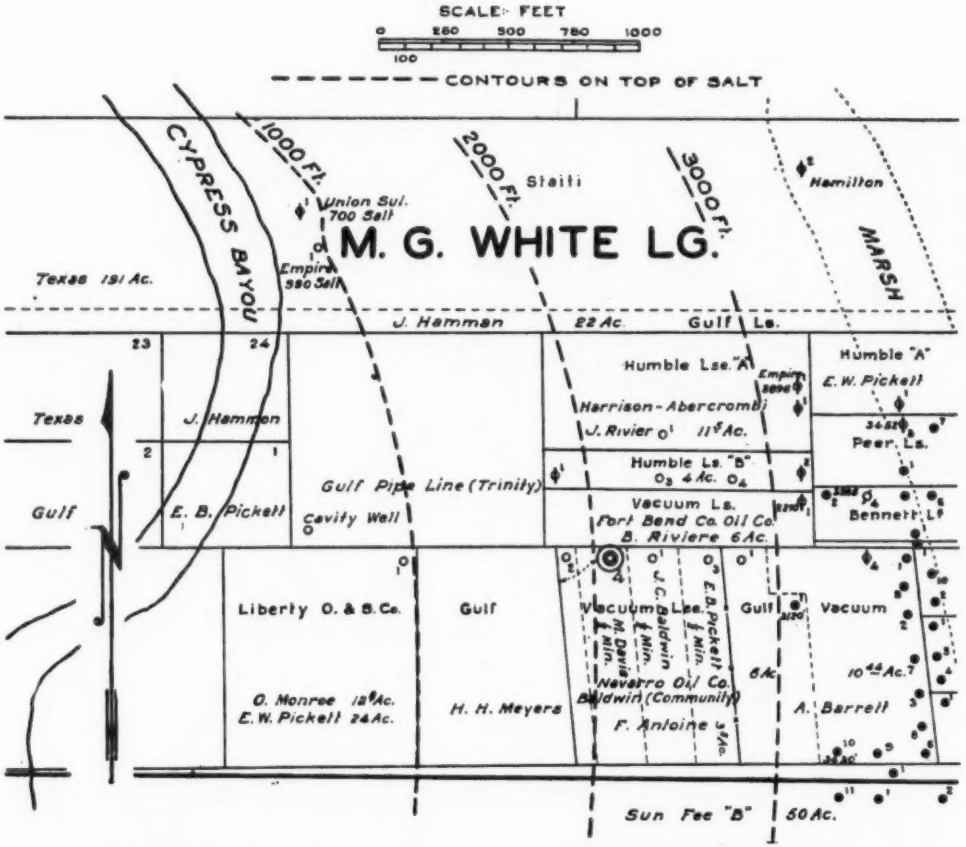

FIG. 1.—Part of South Liberty oil field, Liberty County, Texas, showing location of the Navarro Oil Company's Baldwin (Community) leases and their well No. 4.

FLEMING
LIBBIE
MONTGOMERY
HARDIN
LIBERTY
ORANGE
LOUISIANA
WALLER
HARRIS
BEAUMONT
CLAY
JEFFERSON
SABINE LAKE
RECENT
HOUSTON
CHAMBERS
GALVESTON BAY
FORT BEND
GALVESTON
BRAZORIA
GULF OF MEXICO
MATAGORDA
BAY CITY
SALT DOMES
OF
SOUTHEAST TEXAS
SOUTH LIBERTY
SALT DOME
SCALE IN MILES
1. ORANGE ?
2. SPINDLE TOP
3. FANNETTE
4. BIG HILL
5. SOUR LAKE
6. HIGH ISLAND
7. SARATOGA
8. BATSON
9. HULL
10. MOSS BLUFF
11. SOUTH LIBERTY
12. LOST LAKE
13. DAVIS HILL
14. BARBERS HILL
15. NORTH DAYTON
16. GOOSE CREEK ?
17. HOSKINS MOUND
18. HUMBLE
19. STRATTON RIDGE
20. PIERCE JUNCTION
21. BRYAN HEIGHTS
22. BLUE RIDGE
23. ALLEN
24. CLEMENS
25. SUGARLAND
26. WEST COLUMBIA
27. NASH
28. HAWKINSVILLE
29. LONG POINT
30. DAMON
31. BIG CREEK
32. HOCKLEY
33. BIG HILL
34. BOLING
35. ORCHARD
36. BROOKSHIRE
37. MARKHAM

FIG. 2

Charles Stewart, of the Navarro Oil Company, was on the floor of the Community well No. 4 a few minutes after the core section was taken and carried these samples to Mr. Cashin who submitted them for analysis. The writer washed the samples, made the description and ascertained the age on May 6, 1929, and later acquired a duplicate set from Mr. Cashin's collection, the analysis of these corroborating the first determination.

There is no evidence of either metamorphism or great pressure in this Cretaceous rock other than the slight dolomitization of the limestone and the brecciated condition of the marl.

In conclusion, attention should be called to the following:

1. That the salt found in at least one of the Gulf Coast salt domes of Texas has its source in formations as old as, or older than, the upper part of the Upper Cretaceous.

2. That the crystalline limestone forming a part of the cap rock on at least one of the salt domes in the Gulf Coast area of Texas, as revealed by this analysis, is original sediment representing a part of original bedded deposits carried upward by the intrusive salt and is therefore not a chemical precipitate or a formation of secondary origin.

3. That this marl in its present position near the top of the salt stock has not been metamorphosed to any great extent by heat or pressure.

The writer wishes to acknowledge the constructive criticism and advice given by Wallace E. Pratt, and to thank D'Arcy M. Cashin, chief geologist for the Navarro Oil Company, for his permission to publish this information.

T. E. MORRISON
Paleontologist

HUMBLE OIL AND REFINING COMPANY
HOUSTON, TEXAS
May, 1929

CONCHO BLUFFS OF CRANE, ECTOR, AND WINKLER COUNTIES, TEXAS

The Concho Bluffs, which form a west-facing Cretaceous escarpment extending northwest and southeast through Crane, Ector, and Winkler counties, Texas, were mapped with plane table and alidade in April, 1926, by the writer assisted by Larry Seaman (Fig. 1). It represents the western edge of the Staked Plains. Since structure in the Permian "Big lime" elsewhere on the west side of the Permian basin was known to be reflected in Cretaceous rocks on the surface, it was

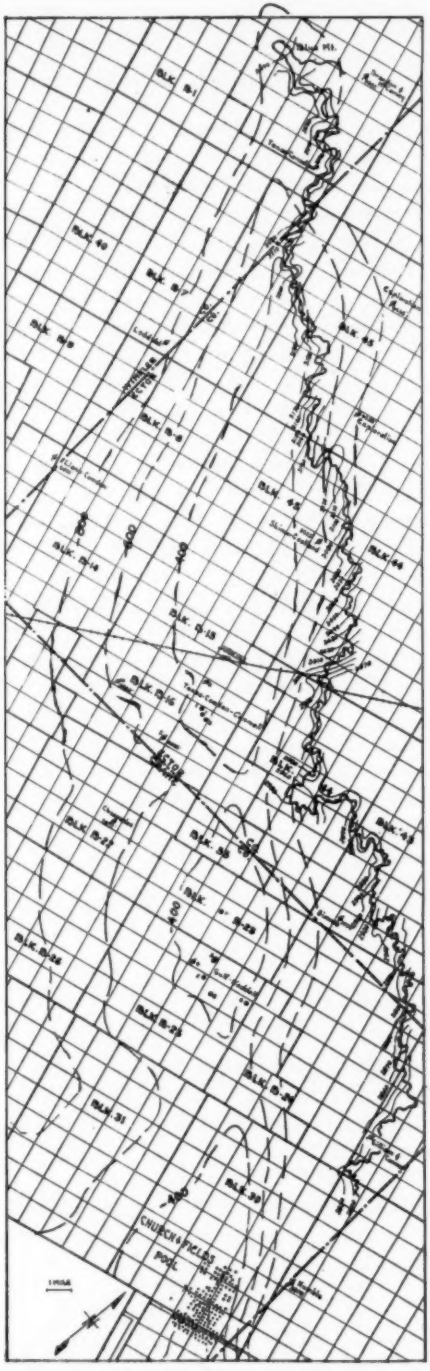

FIG. 1.—Map of surface and subsurface structure in vicinity of Concho Bluffs in Crane, Ector, and Winkler counties, Texas. Contour interval, surface, 10 feet; subsurface, 200 feet. Datum, sea-level.

hoped that this escarpment might help in locating the McCamey-Church and Fields trend as it continued toward the northwest, the Church and Fields pool being at the extreme south end of the area mapped.

The Cretaceous series lie unconformably on Triassic beds. The section used was as follows:

Edwards lime	Alternating hard and soft lime; 50-75 feet exposed in escarpment
	Gray limestone 1 foot to 2 feet thick, 7 feet above top of yellow sandy lime
	Yellow sandy limestone 4-6 feet thick
Walnut clay	Maximum thickness, 3 feet
Trinity or Basement sand—complete section not exposed	
Unconformity	
Triassic	

The contact of the Trinity sand and Edwards lime was used as datum for the 10-foot contours as shown on the accompanying map. The heavy broken contours have an interval of 200 feet and are on the top of the Permian "Big lime," and suggest the subsurface trend of the Church and Fields-Waddell-Connell fold.

It is the writer's opinion that there is a very definite relation here between structure in the Permian lime and in the Cretaceous beds. The escarpment appears to parallel the Permian fold and to lie on its east flank.

JOSEPH M. WILSON

DALLAS, TEXAS
July, 1929

THE BY-PASSING AND DISCONTINUOUS DEPOSITION OF SEDIMENTARY MATERIALS

The following corrections of typographical errors should be made in the article on "The By-Passing and Discontinuous Deposition of Sedimentary Materials" by J. E. Eaton in the July *Bulletin*, page 741.

In line 1 of the quotation: ***continents***, not continuents.

In line 16 of the quotation: ***continents***, not constituents.

DISCUSSION

AGE OF BROWNSTOWN MARL OF ARKANSAS[1]

In the June number of Volume 13 of this *Bulletin* Merle C. Israelsky published a brief note in which he correlated the Brownstown marl of Arkansas with the Bonham clay of northeast Texas. The correlation is based on a micro-faunal assemblage in the Brownstown similar to that occurring in the Bonham. He does not list this assemblage, nor does he cite specific localities from which the micro-faunas were obtained either in the Brownstown or Bonham.

In the vicinity of Bonham, Fannin County, Texas, no sharp line of demarcation has been established by me between the Bonham clay and overlying marl which is commonly correlated with the Brownstown marl, although a bed of glauconitic clay observed at two or three localities south and southeast of town is believed to represent the Blossom sand which, farther east in Lamar and Red River counties, Texas, intervenes between the Bonham and the Brownstown. It would be possible, therefore, to collect a sample near Bonham, which, though supposed to be from the Bonham, would actually be from the overlying marl which has been correlated with the Brownstown. It would also be possible to collect a sample from the basal part of the Bonham, which would be several hundred feet stratigraphically lower and might contain a very different faunal assemblage from that in the first sample. In making faunal comparisons of this kind, which involve revisions of previously accepted correlations, it is essential that the specific localities from which the fossils were obtained be cited and faunal lists be given.

In making this new correlation, Mr. Israelsky assumes that the Bonham clay carries a characteristic, restricted micro-faunal assemblage of known composition. Is this an established fact? Or may not a micro-faunal assemblage present in a marl facies of the Bonham clay, reappear in similar younger marls at higher stratigraphic levels? If this possibility is admitted, the finding of a micro-faunal assemblage in the Brownstown of Arkansas similar to one in the Bonham clay of Texas would hardly be conclusive proof of the Bonham age of the Brownstown.

North of Paris, in Lamar County, Texas, where the Bonham clay underlies the Blossom sand, the clay is divisible into a lower marl member and an upper clay member which carries but little calcium carbonate. The lower marl member carries *Gryphaea aucella* Roemer, *Ostrea congesta* Conrad, and fragments of a large thick-shelled *Inoceramus;* this is an Austin chalk fauna. This assemblage of fossils was found in numerous exposures in Lamar County along the roads leading northwest to Direct and Garretts Bluff, 6-14 miles from Paris, along the Arthurs City road, 3-7 miles north of Paris, and in the vicinity of Faught, 8.5-13 miles northeast of Paris; also along the Woodland road, 6.5 -9 miles north of Detroit, Red River County. Aside from paleontologic considerations, the field relations hardly admit of this marl being as young as

[1]Published by permission of the director, U. S. Geological Survey.

the Brownstown marl of Arkansas. Has Mr. Israelsky compared the microfossils from this lower Bonham with those from the Brownstown of Arkansas?

Near the base of the Brownstown marl, a mile northeast of Ben Lomond, Sevier County, Arkansas, I found a *Scaphites* which J. B. Reeside has identified as *S. hippocrepis* Morton. This species occurs in the Eagle sandstone (lower Pierre age) of the Western Interior, in the lower part of the Anacacho limestone (lower Taylor age) in Texas, in the Merchantville clay (lower Taylor age) of New Jersey, and in the upper Santonian of Europe. This species, and the absence of the larger characteristic fossils of the Austin chalk, affords a reasonable basis for correlating the Brownstown of Arkansas with the lower Taylor of Texas.

Mr. Israelsky suggests the possibility that the Tokio formation may be of Eagle Ford age, though he cites no evidence in favor of such a correlation other than the position of the Tokio below the Brownstown. The upper part of the Tokio near Ben Lomond has yielded an elongated species of *Inoceramus* which several of our best authorities on Mesozoic fossils consider as definitely younger than the Eagle Ford. The lower parts of the Tokio have yielded poorly preserved fossil mollusks, any or all of which might occur in beds younger than the Eagle Ford, but none of which is known in beds of undoubted Eagle Ford age. Detailed localities and lists are given by C. H. Dane in a report now in press as a bulletin of the Arkansas Geological Survey. None of the many characteristic Eagle Ford fossils has been recognized in the Tokio. The field relations strongly suggest that the Bonham clay and the Blossom sand of northeast Texas together represent the Tokio.

The Tombigbee sand of the eastern Gulf region, to which Mr. Israelsky refers, was formerly correlated by me with the upper part of the Austin, but in a recent paper[1] I referred it to the lower Taylor, on the basis of its contained larger fossils.

It behooves all of us to be open-minded on the subject of correlation of the Upper Cretaceous formations of the Gulf region; in the light of new evidence we must sometimes change our earlier opinions about the age equivalences of formation units in different parts of the area. It is the truth we are after. But in this instance the evidence, as presented, is not convincing, and is in direct conflict with that afforded by other fossils.

LLOYD W. STEPHENSON
Chief, Section of Coastal Plain Investigations

U. S. GEOLOGICAL SURVEY
June 24, 1929

STUDIES IN DIFFERENTIAL COMPACTION

The experiments of Nevin and Sherrill[2] fail to duplicate the conditions of nature in one very important respect.

[1]L. W. Stephenson, *Amer. Jour. Sci.*, Vol. 16 (1928), p. 492.

[2]C. M. Nevin and R. E. Sherrill, "Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 1 (January, 1929), pp. 1-22.

Walcott[1] has estimated the average rate of deposition of sediments to be 1 foot in 50 years. Barrell[2] considered this estimated rate to be at least fifteen times too large. The burial of a hill 100 feet or more in height would require a great many years. The compaction of sediments begins immediately on deposition. King[3] recognized that compaction of a clay will take place partly by the load of accumulating sediment above. It is evident that the burial of a hill will take a great many years and that compaction takes place throughout the time of deposition. In the experiments of Nevin and Sherrill it appears that the hill was covered by the first pouring of sediments which were then allowed to settle. If their hard object represents a buried hill, their experiment simulates the deposition of 100 feet or more of sediment over night. If their experiment simulates normal deposition, the hard object represents a small pebble.

Lewis[4] notes that the porosity of freshly deposited Hudson River silts may be as much as 88 per cent, although silts buried to a depth of 50 feet have

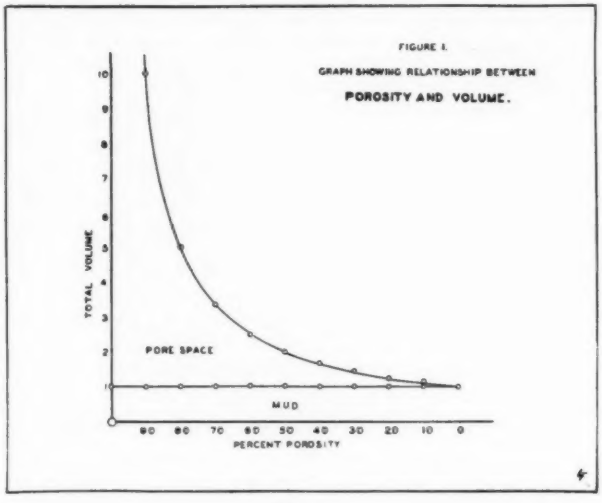

FIG. 1

[1]C. D. Walcott, *Smithsonian Report for 1893* (1893), pp. 310-14; *Jour. Geol.*, Vol. 1 (1893), pp. 639-76.

[2]Joseph Barrell, "Rhythms and Measurements of Geologic Time," *Bull. Geol. Soc. Amer.*, Vol. 28, p. 817.

[3]F. H. King, "Principles and Conditions of the Movements of Ground Water," *U. S. Geol. Survey 19th Ann. Rept.* (1899), p. 78.

[4]J. V. Lewis, "The Fissility of Shale and its Relation to Petroleum," *Bull. Geol. Soc. Amer.*, Vol. 35 (1925), pp. 557-90.

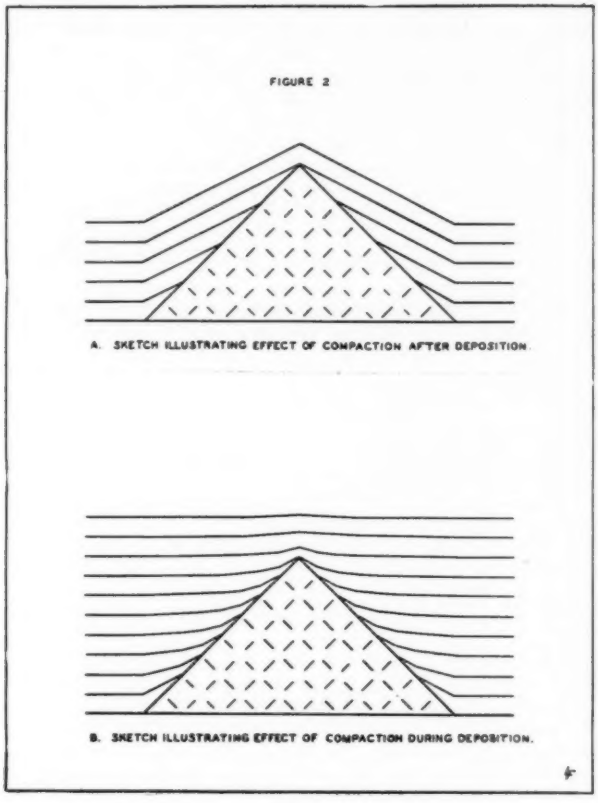
FIGURE 2
A. SKETCH ILLUSTRATING EFFECT OF COMPACTION AFTER DEPOSITION
B. SKETCH ILLUSTRATING EFFECT OF COMPACTION DURING DEPOSITION.

FIG. 2

a porosity of only 55 per cent. The relationship between changes in porosity and changes in volume is shown in Figure 1, which shows the case of a fixed amount of solid matter mixed with varying amounts of water. It will be seen that a reduction of porosity from 88 per cent to 50 per cent involves a loss in volume of 76 per cent. This takes place by the time the silt is buried to a depth of 50 feet. It will be noticed that a reduction of porosity from 50 per cent to 20 per cent involves a loss of 9.6 per cent of the original volume. A further reduction from 20 per cent to 10 per cent porosity involves a loss of 1.2 per cent of the original volume. The loss of volume on compaction of a silt to a shale of 20 per cent porosity is 85 per cent of the original volume. Of the total loss of volume, 88 per cent takes place during the first 50 feet of burial.

The effect of compaction during deposition is illustrated in Figure 2. It is apparent that compaction during deposition will lessen greatly the tendency of differential compaction to cause arching in the beds overlying a buried hill.

It is concluded that the experiments of Nevin and Sherrill fail to reproduce the conditions of nature, and that they give an exaggerated idea of the importance of differential compaction in the formation of folding in sedimentary rocks.

LYNDON L. FOLEY

TULSA, OKLAHOMA
July 2, 1929

JOHN RAY NOT JOHN WRAY

In the interest of accuracy and in order to keep the record straight, permit me to recite a few facts relative to the name John Ray, which name is usually applied to the large structure located chiefly in northeastern Potter and southeastern Moore counties in the Panhandle of Texas.

The name John Ray was first applied to a creek which rises in the edge of the Tertiary plains north of South Canadian River and flows southwest, crossing the sand hills, into Canadian River a few miles above the bridge on the highway 20 miles north of Amarillo. The old-timers tell me that the creek was named for an old-time cattle man, John Ray, who established a ranch near the mouth of this creek in the late seventies or early eighties.

Near the head of John Ray Creek is a flat-topped butte, capped with caliche, an outlier of the high plains Tertiary, which came to be known as John Ray Butte. For many years it was a prominent landmark for the cattle man. On a clear day the butte may be seen from Amarillo, 30 miles distant toward the south.

In 1917 I was employed by M. C. Nobles and associates of Amarillo who afterward formed the Amarillo Oil Company, to map the structure in northeastern Potter County, which structure I had first noticed when in the employ of the U. S. Geological Survey in 1905 and described, but not named, in Water Supply Paper 191. The detailed field work outlining the dome was accomplished in March, 1917, by Robert S. Dewey. The greater part of the dome was found to be on the ranch then owned by R. B. Masterson. We discussed the matter of naming this the Masterson dome, but preferred the use of a natural object rather than that of an individual. We chose the name John Ray dome for the reason that the John Ray butte lay near the apex of the structure.

So far as I know the first printed mention of this dome in geologic literature occurs in this *Bulletin*, Volume 4, Number 3, page 269. In the article the name is correctly spelled John Ray.

During the past few years I have frequently noticed in various geologic articles the incorrect spelling of this name. The last example is in the very excellent article on helium in the Amarillo field by Ruedemann and Oles in the July, 1929, issue of the *Bulletin*, Volume 13, Number 7, page 799. In this article the name is consistently but incorrectly spelled John Wray. Just who was the first sinner in this regard I do not happen to know.

CHARLES N. GOULD

NORMAN, OKLAHOMA
JULY 17, 1920

RESEARCH NOTES

A. A. P. G. RESEARCH COMMITTEE

(Members' terms expire immediately after annual Association meetings of the years shown)

ALEX W. MCCOY, *chairman*, 919 East Grand Avenue, Ponca City, Okla.

1930:
D. C. BARTON, Petroleum Bldg., Houston, Tex.
R. C. MOORE, Univ. of Kansas, Lawrence, Kan.
W. T. THOM, JR., Princeton Univ., Princeton, N. J.
F. M. VAN TUYL, School of Mines, Golden, Colo.

1931:
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F. H. LAHEE, Box 953, Dallas, Tex.
M. K. READ, 1519 Linda Rosa, Los Angeles, Calif.
F. B. PLUMMER, Bur. Econ. Geology, Austin, Tex.

1932:
C. R. Fettke, 1118 Wightman, Pittsburgh, Pa.
A. I. LEVORSEN, Box 1830, Tulsa, Okla.
SIDNEY POWERS, Box 2022, Tulsa, Okla.
R. D. REED, 1717 South Third, Alhambra, Calif.
L. C. SNIDER, 60 Wall Street, New York, N. Y.
W. C. SPOONER, Box 1195, Shreveport, La.
W. E. WRATHER, 4300 Overhill Dr., Dallas, Tex.

The purpose of the Research Committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the Research Committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the Committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The Committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

A meeting of the Research Committee is announced for August 29, 30, and 31, 1929, at Tulsa, Oklahoma, with hotel headquarters at the Mayo. Members of the Association are welcome.

CORALLINE ALGAE, GUADALUPE MOUNTAINS[1]

The coralline algae appear mostly as more or less rounded balls, ranging from the size of a pea to that of a cabbage head and showing concentric structure. The proof of their algal nature is in their microscopic structure. Much of the limestone of the Guadalupe range consists of such variously shaped nodules, mostly of smaller size. Girty in his monograph refers to the "pisolitic structure" of the limestone. Somebody ought to take up the study of these coralline algae. They are the most important limestone formers in the world, and in Europe fully recognized as such, for example in England, where Garwood has described them as rock builders in the Carboniferous; but in America they have been generally overlooked, with the exception perhaps of the so-called

[1]Copy of letter from Rudolf Ruedemann to Sidney Powers, dated May 22, 1929.

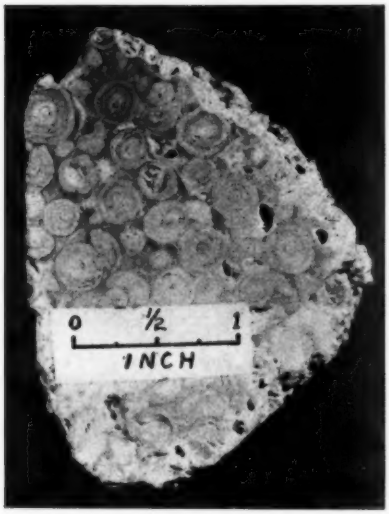

FIG. 1—Algal limestone. "Sample from north wall of canyon (near mouth), on road leading to Carlsbad Caverns."

Algonkian algae, described by Walcott which, according to European authors, are probably inorganic.

It seems to me the problem of the algal reefs in the southwest is a big one and also very important for the oil geologist—one that should be undertaken by a competent man. It would require studying much of the limestone both in the field and in thin sections.

RUDOLF RUEDEMANN
State Paleontologist

ALBANY, NEW YORK
May 22, 1929

REVIEWS AND NEW PUBLICATIONS

Petroleum Development and Technology, 1928-29. By the Petroleum Division, American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York, N. Y., 1929. 623 pp., illustrated, cloth. 6 x 9 inches. Price, $5.00.

In this volume, A. W. Ambrose, chairman of the Petroleum Division of the A. I. M. M. E. of 1928, transmits fifty-one technical papers on petroleum development and technology, which were presented at the meetings of the A. I. M. M. E. in Tulsa last October and in New York last February.

One is primarily struck with the immensity of the work. All phases of the industry in this country, and in separate papers foreign petroleum production conditions, are fully covered by writers whom we all recognize as foremost authorities. In addition are contributions and the discussions of subjects which are really directly connected with petroleum engineering, but which until lately may not have been fully enough recognized by engineers. These are classified under Petroleum Economics, and The Need for Petroleum Engineering Education. Petroleum Refining and Gas Transportation also come in for thorough discussion.

It would be presumption to assume that a reviewer could satisfactorily summarize a publication of this broad scope in a few words. Aside from the papers themselves, the opinions advanced in the discussions (published) by technologists and geologists of note, touching as they do practically all of the problems of the oil industry of to-day, make it necessary for one who wishes to keep up with the times, to add this book to his library and consult it frequently.

Each reader will be impressed with some particular subject in which he is interested. Selecting from the papers, therefore, this reviewer wishes to call especial attention to the first three papers: "Rotary Drilling Problems," by R. S. Cartwright; "Underground Surveys of Oil Wells," by Alexander Anderson; and "Acid Bottle Method of Subsurface Well Survey," by E. H. Griswold. In these, the subject of crooked holes, which has lately occupied attention, and which is a vital fundamental problem of the entire industry, now in process of constructive correction, is presented. That it is important to all, is shown by the discussions and the men discussing it. Every geologist should read at least three paragraphs in the discussion (page 48) by F. H. Lahee. He there sums up the situation in all its bearings, as it affects not only the financier, the producer, and the driller, but also the technologist, the appraiser, and the geologist, who may base sincere conclusions on an insecure, uncertain premise.

J. B. Umpleby, chairman of the Petroleum Division for 1929, presents plans for this year which contemplate three meetings instead of two. One of these will be in Los Angeles, another, at the time of the Petroleum Exposition, at Tulsa, and a third in New York, at the annual meeting. The outlook is for

an even more comprehensive, thorough volume of Petroleum Development and Technology for 1929 to 1930.

H. B. GOODRICH
Petroleum Engineer

TULSA, OKLAHOMA
June 21, 1929

RECENT PUBLICATIONS

CALIFORNIA

"The Santa Barbara Mesa Discovery," by J. L. Chase. *Oil Bulletin* (Los Angeles, July, 1929), pp. 690-93, illus.

COLOMBIA

"Tertiary Fossil Plants from Colombia, South America," by Edward W. Berry. *Proc. U. S. Natl. Museum*, Vol. 75, Art. 24, No. 2795 (Washington, D. C., 1929), 12 pp., 5 pls.

COLORADO

"Bibliography of the Geology of South Central Colorado," by J. Harlan Johnson. *Colorado School of Mines Quart.* (Golden, October, 1928), Vol. 23, No. 4, 30 pp.

CROOKED HOLES

"Crooked and Drifting Holes, Causes, Effects, and Some Suggested Remedies," by H. W. Westsmith and Laurence R. Cook. *Oil Bulletin* (Los Angeles) June, 1929), pp. 577-86.

"Correcting Crooked Holes at Barbers Hill," by P. C. Murphy. *Oil Weekly* (July 19, 1929), p. 31.

"Crooked Holes and Other Crooks," by C. S. Thomas. *Oil Bulletin* (Los Angeles, July, 1929), pp. 698 and 767, illus.

FLORIDA

"Geology of Florida with Geologic Map," by C. Wythe Cooke and Stuart Mossom. *Florida Geol. Survey 20th Ann. Rept.* (Tallahassee, 1929). 200 pp. Price (postage), $0.10.

GENERAL

Report III of the Federal Oil Conservation Board (February 25, 1929), 218 pp. Appendix C, pp. 50-218: "Petroleum Resources of Foreign Countries and Outlying Possessions of the United States," by Arthur H. Redfield. Supt. of Documents, Washington, D. C. Price, $0.30.

"Experimental Work on Red-Bed Bleaching," by W. D. Keller. *Amer. Jour. Sci.* (July, 1929), pp. 64-70.

"Pagecrinus, a new Crinoid genus from the American Devonian," by Edwin Kirk. *Proc. U. S. Natl. Museum*, Vol. 75, Art. 22, No. 2793 (1929), 4 pp., 1 pl.

"Additions to the Flora of the Green River Formation," by R. W. Brown. *U. S. Geol. Survey Prof. Paper 154-J* (1929), pp. 279-99, Pls. 70-76. Supt. of Documents, Washington, D. C. Price, $0.20.

"Recent Articles on Petroleum and Allied Substances," bibliography compiled by *U. S. Bur. Mines* in coöperation with *Amer. Petrol. Institute* and *Special Libraries Association* (May, 1929), 57 mimeographed pp. Distributed by Petroleum Field Office, U. S. Bur. Mines, 506 Custom House, San Francisco, California.

GEOPHYSICS

Geophysical Abstracts, No. 1, by Frederick W. Lee. *U. S. Bur. Mines Information Circular 6120* (May, 1929). Washington, D. C. Free.

"Geophysical Instruments and Methods," by Mark C. Malamphy. *Oil Weekly* (July 12, 1929), pp. 31, 32, 72, and 74.

International Geological Congress, 4th Volume, Proceedings of 14th session, Madrid, 1926 (1929), pp. 1368-2152, illus. Section on geophysics, pp. 1497-1781, papers by Huelin; Kossmat; de Barandica and del Bosch; Quirke; Kindelán; Gil and Ruiz; Nikiforoff; Ambronn; Salfeld; Neumann; Krahmann; Barandica, Siñeriz, del Bosch, Gil Huelin; Weinzierl; Mouchkétoff; Gavelin; Arctowski, Reinecke; and Nikiforoff.

GERMANY

"Über die Bedeutung der Regressivbewegungen der Karpathen und ihres Vorlandes für Erdölaufschluss," by W. Teisseyre. *Petrol. Zeit.* (Vienna, July 3, 1929), pp. 925-32, Figs. 1-2.

"Einige Betrachtungen über Salzlager, Salzhorste und Erdöl," by A. F. v. Stahl. *Petrol. Zeit.* (Vienna, July 3, 1929), pp. 948-49.

"Die Ältere Salzfolge Mitteldeutschlands unter besonderer Berücksichtigung des Unstrutgesichtes," by Anton Tinnes. *Preuss. Geol. Landesanstalt* (Berlin, 1928), Archiv für Lagerstättenforschung, Heft 38, illus.

INDIA

"Note on the Joya Mair Dome Fold, near Chakwal, Jhelum District, Punjab," by D. N. Wadia. *Records Geol. Survey of India*, Vol. 61, Pt. 4 (Calcutta, March, 1929), pp. 358-61, Pl. 29.

KANSAS

"An Interesting Kansas Cross Section," by W. A. Spinney. *Oil and Gas Jour.* (July 11, 1929), pp. 118-19. Structural section prepared by the *Kansas Geol. Survey.*

MEXICO

"Descriptions of New Species of *Foraminifera* of the Genus Discocyclina from the Eocene of Mexico," by Thomas Wayland Vaughan. *Proc. U. S. National Museum*, Vol. 76, Art. 3 (1929), pp. 1-18, pls. 1-7.

RUMANIA

Die Rumänischen Erdöllagerstätten, by Karl Krejci. Ferdinand Enke (Stuttgart, Germany, 1929). 140 pp., 43 illus. Price, Rm, 15.

TEXAS

"New Fossil Land and Fresh-Water Mollusks from the Reynosa Formation of Texas," by William B. Marshall. *Proc. U. S. Natl. Museum*, Vol. 76, Art. 1, No. 2798 (1929), 6 pp., 1 pl.

TRINIDAD

"The Chemical Investigation of Trinidad Well Waters and Its Geological and Economical Significance," by J. S. Parker and C. A. P. Southwell. *Jour. Inst. Petrol. Tech.* (April, 1929), pp. 138-82, Figs. 1-10.

WYOMING

"New Map of Big Sand Draw Gas Field, Wyoming," by C. E. Dobbin and G. H. Cronin. *U. S. Geol. Survey* (Washington, D. C., 1929). May also be obtained at 508 Consolidated Royalty Building, Casper, Wyoming. Free.

"Coal and Oil in Hanna and Carbon Counties, Wyoming," by C. E. Dobbin, C. F. Bowen, and H. W. Hoots. *U. S. Geol. Survey Bull. 804* (1929).

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of the applicant.)

FOR ACTIVE MEMBERSHIP

Nels C. Beck, Fort Worth, Tex.
E. L. Porch, Jr., D. R. Semmes, Elfred Beck

Phil E. Blackwelder, Garden City, Kan.
Frank C. Greene, T. K. Harnsberger, J. B. Leiser

Wheaton C. Clark, Tulsa, Okla.
A. W. Duston, Robert J. Davis, A. I. Levorsen

H. Gordon Damon, Austin, Tex.
Fred M. Bullard, F. W. Simonds, F. L. Whitney

Dwight A. Dechman, Los Angeles, Calif.
R. P. McLaughlin, Bartlett W. Gillespie, John S. McKenna

Cecil Drake, Tampico, Mexico
G. F. Kaufmann, R. D. Vernon, H. E. Thalmann

Andrew Gilmour, Bakersfield, Calif.
Donald C. Barton, E. H. McCollough, Dollie Radler

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Headquarters has been unable to get replies from the members here listed. Their last known addresses are given. Correct addresses will be appreciated if sent to Association headquarters, Box 1852, Tulsa Oklahoma.

Active Members

Albert C. Price, Shell Petroleum Corporation, Houston, Texas
Gene R. Smith, Suite 752, Subway Terminal Building, Los Angeles, Calif.

Associate Members

D. Carleton Jones, 1340 East Colorado Boulevard, Glendale, California
Hugh McElwee Kent, 235 N. Bright Avenue, Whittier, California
Cecil C. Pease, 1261 Buchanan Street, Topeka, Kansas

EMPLOYMENT

Inquiries are received at Association headquarters for information about geologists who are available for many different positions. Men who are looking for work and heads of departments of oil companies who are looking for men might be assisted by writing to headquarters for a special form for recording their needs. Association membership is an aid to the man looking for a position. Address, Box 1852, Tulsa, Oklahoma.

Memorial

M. WOOD STANLEY

M. Wood Stanley was born at Ozark, Arkansas, June 23, 1893. He attended Missouri Valley College, 1911-12, Cumberland University, 1912-13, and in 1914-15 majored in geology at the University of Arkansas. From 1915 to 1917, he was geologist for the Gypsy Oil Company, working in Oklahoma, Kansas, Arkansas, and Texas. During the war, he was an instructor in topographic mapping at Camp Pike, Arkansas, being commissioned a second lieutenant.

In 1919 to 1921, Stanley was geologist for the Goodrich Oil Company. In the fall of 1921, he came to Texas for the Gulf Production Company. He worked out from the Corsicana office and first found and mapped the Mt. Calm fault in Hill County, on which production has just been found. In March, 1922, he was put in charge of the geological work in the San Antonio office of the Gulf Production Company. He worked in this section of Texas until the fall of 1922, when he moved to Corsicana and entered the oil business for himself. He secured leases in the Powell area which shortly proved productive. These were operated by Frank Buttram. Stanley next moved to Dallas. Here, unfortunately, he was threatened with tuberculosis and had to move back to San Antonio and from there to the higher climate of El Paso.

In the winter of 1928, Wood moved back to a lower altitude, and engaged in farming at Dilley, Texas. He suffered greatly from asthma, and on April 27, 1929, he died there.

One of the most outstanding characteristics of Wood Stanley was his sterling integrity. In the geological field, he was well known for his marked ability in reconnaissance work. It was the regret of his many friends that poor health in his later years kept him out of active participation in the oil business in which he had started so successfully for himself.

DILWORTH S. HAGER

LOCKHART, TEXAS
June, 1929

AT HOME AND ABROAD

LYMAN C. REED, of Houston, Texas, resigned from the Rio Bravo Oil Company, effective July 1, to accept a position as geologist for the Standard Oil Company, S. A., of Argentina, Buenos Aires.

VAN COURT WARREN, consulting geologist of Los Angeles, describes the Stow anticline, northeast of the Elwood field, California, in *California Oil World* of June 20, 1929.

STUART ST. CLAIR, consulting geologist, has returned from Colorado, Texas, to Hudson View Gardens, 183d Street and Pinehurst Avenue, New York City.

GEORGE V. DUNN resigned his position as chief geologist for the White Eagle Oil and Refining Company, effective July 1, to engage in independent practice at Tulsa, Oklahoma.

E. P. PHILBRICK is in charge of geological work for the White Eagle Oil and Refining Company in the Oklahoma district.

NORBERT T. LINDTROP, chief geologist for the Government Oil Trust "Grosneft," Grozny, U. S. S. R., has a paper on "Underground Conditions of the Formations in the New Grozny Oil Fields," in *The Petroleum Industry* (Russian), No. 4 (1929).

Mr. and Mrs. ROBERT H. DOTT announce the birth of Robert Henry Dott, Jr., on June 2, 1929, at Tulsa, Oklahoma.

ROBERT H. DOTT has resigned his position as paleontologist with the Mid-Continent Petroleum Corporation to become geologist for the Sunray Oil Corporation, Exchange National Bank Building, Tulsa, Oklahoma, effective July 1.

DAVID C. HARRELL, of the Shell Petroleum Corporation, San Antonio, Texas, has left for the Dutch East Indies. He was accompanied by Mrs. Harrell, formerly Miss Oleta May Richey of the Phillips Petroleum Company, San Angelo, Texas.

F. K. FOSTER, of the Sinclair Oil and Gas Company, has been transferred from Wichita Falls to San Angelo, Texas, where he will be in charge of the office for the San Angelo district.

The Geological Society of France is to celebrate the one hundredth anniversary of its founding, at Paris, in June and July, 1930.

The Midland, Texas, Geological Society held its annual West Texas field trip, June 22 and 23. The party assembled at Carlsbad, New Mexico, and spent the first day examining the flank of the Guadalupes, visiting Rattlesnake and McKittrick canyons. After a night at Pine Springs Inn at the foot of Guadalupe Point, the party examined the west side of the Point, Bone Springs Canyon,

and Rocky Arroyo west of Carlsbad. Thirty-seven geologists representing Texas, New Mexico, and Oklahoma composed the party, which was ably led by K. H. CRANDALL of the California Company and FRANK PROUT of the Empire Company.

HOMER H. CHARLES, formerly with the Oklahoma Natural Gas Corporation in Kansas and Oklahoma, has accepted a position in the geological department of the Indian Territory Illuminating Oil Company, Bartlesville, Oklahoma.

SIDNEY PAIGE returned from Venezuela and is associated with E. B. HOPKINS at 25 Broadway, New York City.

SHEPARD W. LOWMAN resigned from the Skelly Oil Company to join the Mid-Continent Petroleum Corporation at Tulsa, Oklahoma.

J. S. STEWART, formerly of the Geological Survey of Canada, has rejoined the geological department of Imperial Oil, Ltd., at Calgary for the summer.

President J. Y. SNYDER has appointed DONALD C. BARTON, geologist and geophysicist, to membership in the general business committee as member-at-large.

S. P. BORDEN, petroleum engineer and geologist, of Shreveport, Louisiana, announces the removal of his offices from the Ardis Building to 721 Slattery Building.

The San Antonio section of the A. A. P. G. held a regular monthly dinner and technical meeting on July 1. F. B. PLUMMER, of the Bureau of Economic Geology at Austin, Texas, presented a paper on "Some Features Other Than Structure Controlling the Positions of Oil Fields Along the Fault Zone." At one of the recent Monday luncheons of the section, D. R. SEMMES talked on the oil possibilities of Alabama.

G. E. WHEELER, formerly of the Empire Oil and Refining Company of Bartlesville, Oklahoma, has accepted a position on the geological staff of the Nordon Corporation in Canada.

M. V. ABRAMOVICH, professor of geology at the Polytechnical Institute of Baku, Russia, and chief geologist for the government oil trust, "Azneft," is in the United States visiting the oil fields.

RUAL B. SWIGER has resigned from the Shell Petroleum Corporation at San Antonio, Texas, and is now associated with the Trinity Drillers, Inc., at San Antonio.

J. E. BRANTLY, who has been with the Atlantic Refining Company, Philadelphia, in charge of foreign exploration, is president and operating head and C. R. RIDER is vice-president of a new organization, Drilling and Exploration Company, Inc., associated with E. B. HOPKINS and H. J. WASSON, 25 Broadway, and Petroleum Bond and Share Corporation whose president is JOHN M. LOVEJOY, 39 Broadway, New York City.

ERNEST C. ROSCHEN, of Reisterstown, Maryland, who spent the past year at Johns Hopkins University, Baltimore, Maryland, completing work on a

Ph. D. degree, may now be addressed in care of Companhia de Petroleo de Angola, Loanda, Angola, Africa.

HENRY J. MORGAN, JR., formerly with the Huasteca Petroleum Company at Tampico, Mexico, is now employed by the Atlantic Oil Producing Company, Shreveport, Louisiana.

IONEL I. GARDESCU, who has been studying since January at the University of California, Berkeley, may now be addressed at the Mellon Institute of Industrial Research, Thackeray and O'Hara Streets, Pittsburgh, Pennsylvania.

The forthcoming Drilling Congress (Deuxième Congres International de Forages) will be held in Paris, September 16-23, 1929. Technical sessions include these topics: Prospecting and Investigation of Deposits; Drilling Technique; Economics of Drilling; Legislation Covering Exploration and Drilling. Field trips include Nancy, Homecourt, Strasbourg, and Mulhouse. Further information may be obtained from Schlumberger Electrical Prospecting Methods, 25 Broadway, New York City, or from the secretary, 2d Congres International de Forages, 85 Boulevard du Montparnasse, Paris VI, France.

J. O. NELSON, geologist and geophysicist with the Dixie Oil Company, Inc., Shreveport, Louisiana, has resigned to accept a position on the geological staff of the Lion Oil Refining Company, El Dorado, Arkansas.

M. A. DRESSER has returned from work with the Standard Oil Company at Buenos Aires, Argentina, and is now stationed at Tulsa, Oklahoma, with the Carter Oil Company.

RALPH H. MITCHELL, recently at Suez, Egypt, is now at his home, 48 Nutfield Road, Thornton Heath, Surrey, England.

JAMES HOPKINS, mining engineer and petroleum geologist, has returned from Venezuela and is now connected with The Ethyl Oil Company, 903 Pacific Finance Building, Los Angeles, California.

A. van WEELDEN of the Shell Petroleum Corporation at Dallas, Texas, has been transferred to Holland. Effective August 1, his address will be De Bataafsche Petroleum Maatschappij, 30 Carel van Bylandtlaan, The Hague.

The Petroleum Division of the A. I. M. M. E. will hold a technical program meeting at Tulsa, Oklahoma, October 3 and 4, 1929, in connection with the International Petroleum Exposition, October 5-12. The division will hold a similar meeting at Los Angeles, California, October 4 and 5.

FOREST R. REES, Box 1594, Tulsa, Oklahoma, is compiling a new publication, THE OIL MAN'S SCRAPBOOK, a convenient loose-leaf book containing miscellaneous data of the oil industry including maps and geological and royalty charts. The price is $5.00. Mr. Rees is president of the Oil Properties Corporation.

R. R. POLLAK, engineer for the Signal Oil and Gas Company, died at San Francisco, California, last June.

PAUL B. NICHOLS has returned to the United States after a period of two years as subsurface geologist with the Lago Petroleum Corporation at Mara-

caibo, Venezuela. Mr. Nichols' home address is 1001 West Evans Avenue, Pueblo, Colorado.

FRED M. BULLARD, associate professor of geology and mineralogy in the University of Texas, is a member of the United States Geological Survey Alaskan Expedition this summer. The expedition is in charge of S. R. CAPPS, senior geologist, and the project is combined geologic and topographic work in the region north of Lake Clark.

OLAF P. JENKINS has recently been appointed chief geologist to the California State Division of Mines and Mining, and is taking charge of the newly established geologic branch of this division, which is under the supervision of WALTER W. BRADLEY, state mineralogist. The first duties of the chief geologist are to catalog any published and unpublished material of the state, to evaluate it, to encourage further geological research, and to compile the geology of the state with the ultimate aim of constructing a geologic map of California on the scale of 1:500,000.

JOHN R. REEVES of the Empire Companies, who has been situated at Oil Hill, Kansas, has been sent to the Michigan fields to supervise geological work for his company.

BASIL B. ZAVOICO, consulting geologist of Tulsa, Oklahoma, has an article, "Future of Turbo-Rotary Drilling Has Promising Potentialities." in *Oil Field Engineering* (June 1, 1929).

JOSEPH M. PERKINS, geologist for States Oil Corporation, Eastland, Texas, is now vice-president of the corporation.

DAVID E. MORGAN, geologist with the Dutch-Shell group in Mexico, left Tampico last month for a brief stay in England. His home address is 99 Carmarthen Road Swansea, Wales.

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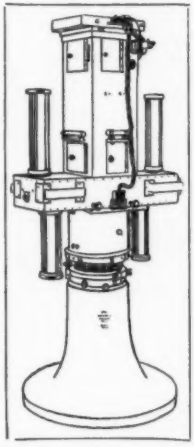

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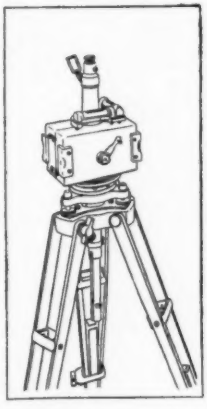

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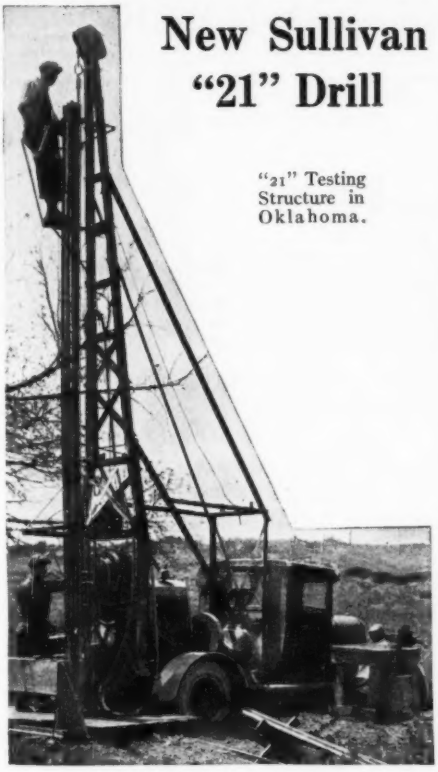

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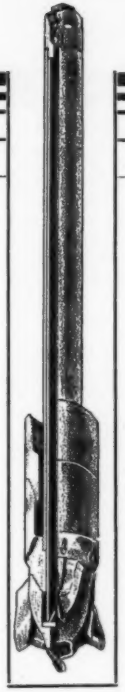

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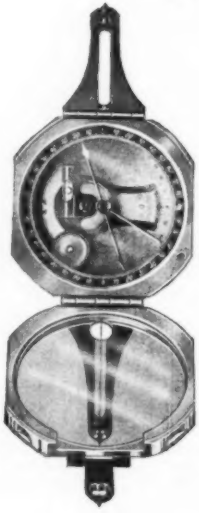

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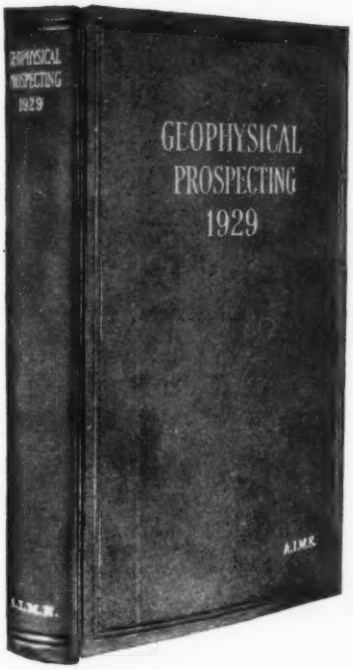

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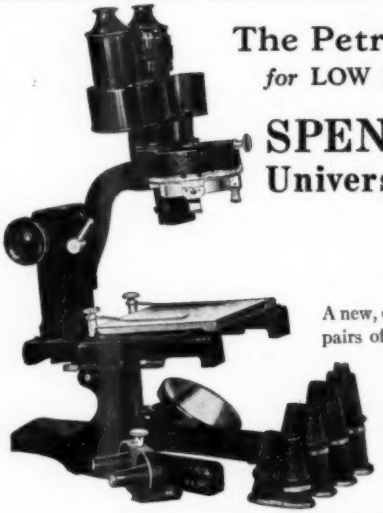

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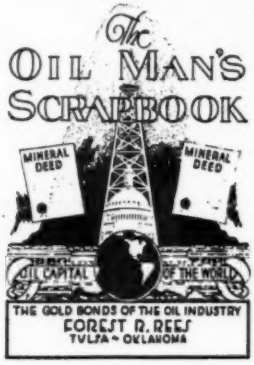

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